THE GEOLOGY AND PETROLOGY OF THE TERTIARY VOLCANIC ROCKS OF THE TAMAR TROUGH NORTHERN TASMANIA

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ABSTRACT

Tertiary volcanic rocks outcrop extensively in the Tamar Trough in four main areas, in which their geological relationships and petrology are mapped and described in detail. They are mainly confined lavas, overlying Palaeocene-Eocene beds and later inter-volcanic sediments and lateritic profiles.

Volcanism commenced in post-Upper Eocene time and continued into at least mid-Tertiary time. Eruptions were spread over about a dozen centres, mostly located on fault lines, and gave volcanic successions up to 500-600 feet thick. Individual flows range from about 30 feet in thickness to coarse lavas several hundred feet thick, containing pegmatitic and differentiated phases and showing some intricate and partly intrusive contacts. The lavas caused drainage diversions and adjustments and yield information on old courses of the Tamar River.

The rocks are mostly undersaturated to nearsaturated alkali olivine-basalts, with minor olivine-nephelinite, nepheline-basanite, limburgite and tholeiitic olivine-basalt. The Tamar suite is, in essence, a typical example of the alkaline volcanic associations of Tasmania.

INTRODUCTION

The volcanic rocks occur along the Tamar Trough, a fault structure formed prior to, or early in, the Tertiary (Longman *et. al.* 1966). This Trough is a locus of Cainozoic drainage and considerable non-marine sedimentation. The volcanic rocks are mainly confined lavas, some of which preserve the course of the ancestral Tamar River at the time of eruption.

Prior to this study, the prevalence of lavas in the Trough was not fully realised, due to localised previous mapping and confusion of coarse grained lavas with the Jurassic dolerite basement. The general distribution, nature and relationships of the lavas were outlined in a preliminary note (Sutherland 1966*a*), and their mineralogy, petrochemistry and magmatic history is discussed elsewhere (Sutherland 1969*b*). This paper deals with the detailed geology and petrography of the lavas, condensed from an M.Sc. thesis submitted to the University of Tasmania (Sutherland 1968).

Access to the area is easy, with both the east and west Tamar served by highways with numerous side roads; much of the area is cultivated, with easy terrain. The author's field mapping commenced in 1963, with aerial photographs on a scale of approximately four inches to the mile. Detailed topographic Lands and Survey maps became available for the area more recently and the geological maps presented here incorporate some control from these.

The author was employed at the Queen Victoria Museum, Launceston, during much of the study and collected specimens are held both there and in the Tasmanian Museum, Hobart. Thin section numbers refer to the Tasmanian Museum catalogued collection. Methods used in determining ranges of optical properties and compositions of minerals, quoted in the petrographic descriptions, are detailed in Sutherland (1969*b*). Mineral modes given were estimated using a microscopic grid and are approximate percentages.

PREVIOUS INVESTIGATIONS AND LITERATURE

Collections of local rocks were made by Lieut. Col. William Paterson with the establishment of European settlement at Port Dalrymple at the beginning of the nineteenth century. Some of this collection is held at the Queen Victoria Museum and is now only of historical importance.

Many of the early geological studies in the Tamar Valley were in the gold mining district of Beaconsfield and contributed little to the knowledge of the Cainozoic rocks, except the deep lead near Cabbage Tree Hill (Scott 1930). Most of these studies are reviewed amongst geological observations on the Tamar Valley (Kershaw 1955, 1958), in the geological mapping of the Beaconsfield square (Green 1959), and in later Tasmanian Mines Department reports (Noldart 1964). Early contributions on the Cainozoic rocks include studies by Johnston (1874, 1875, 1880, 1888), Etheridge (1881), Montgomery (1892) and Twelvetrees (1904), and some give observations on the basalts at Breadalbane and Tamar Heads.

Regional mapping of the Launceston district (Carey 1946), outlined the main features of the Tamar Trough and its geological history. Accurate dating of some of the Tertiary sediments provided some limits for the ages of the Trough and the associated basalts (Gill and Banks 1956; Gill 1962). Several investigations have been made of the Cainozoic sediments at Launceston in regard to foundation conditions (Longman *et. al.* 1966). Further detailed studies on the Tertiary sediments (E. D. Gill pers. comm.) are being prepared for publication by G. D. Aitchison (Commonwealth Scientific and Industrial Research Organisation) and E. D. Gill (National Museum of Victoria). The first petrological studies of the basalts (Johnston 1888; Petterd 1902; Edwards 1950; Green 1959) were limited to scattered samples. In a geomorphological study of the Launceston Tertiary basin, Nicolls (1960) discussed the ages of the basalts in that area and the lateritic surfaces developed on them.

Detailed investigations in some basalt areas provided valuable data. Investigations at Bell Bay commenced with enquiries as to its suitability as a port (Skeets 1922; Launceston Marine Board bore logs). Further investigations for industrial foundation sites included soil tests, seismic profiles and drilling programmes (Polak 1961; McLaren and Taylor 1961; Matthews 1966; Comalco-Bell Bay file reports). Exploratory programmes for a trans-Tamar bridge site by the Tasmanian Mines and Public Works Departments provided geological and sub-surface information on the basalts at Whirlpool Reach (Hughes 1958, 1959; Tasmanian Department of Public Works 1957) and Long Reach (Blake 1960; Maunsell and Partners 1959-1962). The

Beauty Point-Kelso area received attention in connection with wharf and navigational extensions (Launceston Marine Board bore logs) and landslip problems (Blake 1961; Jennings 1964*a*, 1964*b*). Basalt bearing sediments of probably Tertiary age were revealed by Tasmanian Mines Department foundation borings near Perth (Jennings 1965).

Further investigations are being conducted at present by the Tasmanian Department of Mines Geological Survey, as part of the 1" to 1 mile state mapping programme. The Longford Sheet (Blake 1959) was available prior to the present study, with the Launceston Sheet and explanatory report (Longman *et. al.* 1964, 1966) appearing more recently. At the time of writing, mapping of the Beaconsfield and Frankford Sheets is proceeding and will complete the coverage of the Tamar Valley area.

PHYSIOGRAPHY

The Tamar Valley is a broad, drowned, estuarine tract over five miles wide, in which the Tamar River rises from the junction of its North and South Esk tributaries at Launceston and flows some 35 miles out to Bass Strait.

The basalt extrusions have had important physiographic influences. More resistant than the Tertiary sediments, they cap the higher areas. Dissected basalt plateaux reach elevations of 700 feet in the Rosevears area and 600 feet north-west of Hillwood. Lower basalt plateaux, such as in the Bell Bay-Georgetown area at about 100 feet elevation, tend to be buried under younger Cainozoic gravels and sands. In areas lacking basalt extrusions, as between Hillwood and Native Point and between Dilston and Launceston, the Tertiary sediments are eroded to spurs, mostly less than 200 feet in elevation. Above the Tamar's head of erosion at Launceston, the sediments are preserved at higher levels and in the St. Leonards-Breadalbane-White Hills area there are dissected basalt plateau cappings at elevations at about 750 feet, with one small occurrence at about 900 feet.

The extrusions have influenced the course of the Tamar. The river originally appears to have extended further south through Evandale, prior to diversion from the Tamar Trough by lava around Breadalbane, west through Hadspen as the South Esk. Potentially imminent capture of the South Esk by Rose Rivulet at Evandale, however, if made, will re-divert the South Esk back into the Tamar Trough (Carey 1946). There is possible similar past diversion by the basalt flows in the lower Tamar, west through Beaconsfield and out the valley between West and Badger Head. Later extrusion upstream, however, may have diverted the river back to its original course. In contrast, in the middle Tamar the river appears superimposed on the basalt filling its old channel, and these points are discussed later.

Landslips are common in the Tamar Valley and are an important factor in the interpretation of outcrop; heels of slides or inferred slides have been mapped in this investigation. There are active movements above the Tamar's head of erosion at South Launceston (Longman *et. al* 1966) and also at Beauty Point (Blake 1961; Jennings 1964*a*), while historic slides have been recorded near Rosevears (Friend 1849). Erosive action of the Tamar drainage on the unconsolidated Cainozoic beds, with alternations of more permeable gravelly and sandy horizons and less permeable clay horizons, make valley slopes highly unstable; slumping soon becomes evident in new cuttings.

Resistant basalt cappings are wasted by undermining, a process

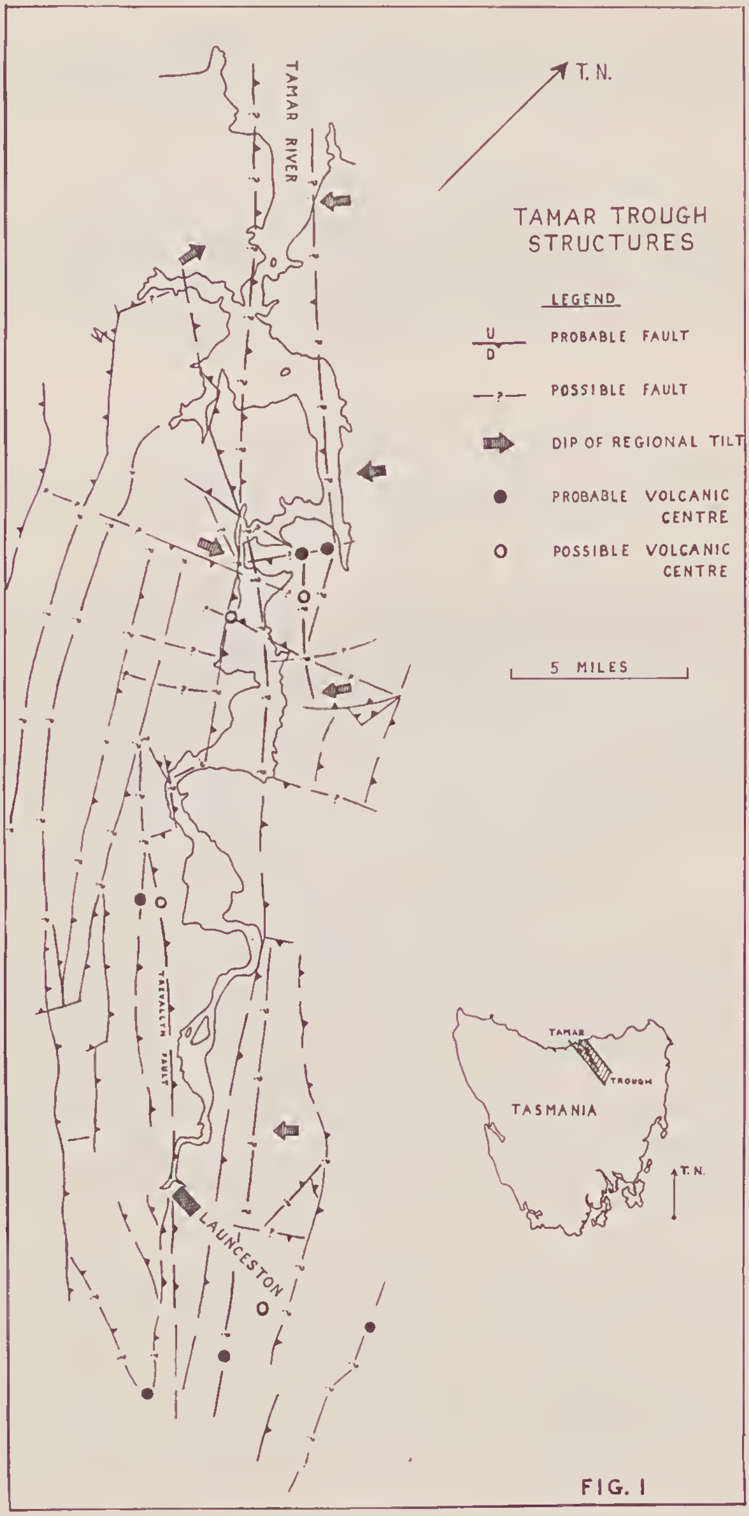


Fig. 1. Structures of the Tamar Trough.

enhanced where the course of the Tamar is superimposed over the old buried channels, so that the basalt base slopes down towards the river on both sides. This, combined with resultant overhanging of columnar and block jointing in the basalt normal to the base and downward slope of sheet jointing parallel to the base, provides extremely favourable conditions for movements. Failure takes place both by backward rotational sliding and by forward toppling, and valley sides in these areas have widespread mantles of basalt float. Large and extensive slides show toes with rocks rotated to near vertical positions. Very large blocks occur amongst the talus debris around Rosevears and Craigburn, and gaps amongst these form ravines and cavern systems, extending to depths of over 50 feet. The bushranger Brady is reputed to have exploited these features, keeping a watch for troopers from the basalt tor that bears his name and then eluding them by hiding in the caverns.

The future development of the Tamar Valley will require an increasing awareness of the widespread instability of much of the valley sides. Here may be mentioned the recommendations of restricted building zones at Beauty Point (Jennings 1964*a*), road shorings along highways, as between Muddy Creek and Rosevears, and the unconventional design of the trans-Tamar Batman Bridge, allowing minimum loading on the potentially more unstable eastern shore.

THE STRUCTURAL AND STRATIGRAPHIC ENVIRONMENT

THE BASEMENT STRUCTURE

The basement rocks are Permo-Triassic strata intruded by sheets of Jurassic dolerite. The dominant structure is the Tamar Trough, a north-westerly trending fault trough associated with late Mesozoic or early Tertiary vertical faulting and tilting (fig. 1). Cross sections in the Launceston area (Longman *et. al.* 1966) show south-westerly down-tilting of the basement of 5-20°, with the Trevallyn Fault marking the axis of a fault wedge and up throwing the western side. The author's mapping to the north indicates that the structure continues beyond the Tamar mouth, but differs in that the western side is down-tilted to the north-east, in opposition to the south-west tilt of the eastern side, and may pass into a graben north of Hillwood.

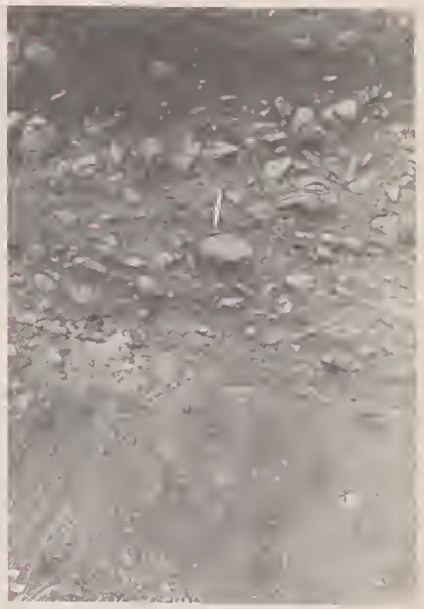
North-easterly tilts in the basement are first encountered north of Rosevears. The structural change appears to be associated with side-stepping of the Trevallyn Fault and a change in the form of the dolerite sheet, which to the north forms a long narrow body extending to West Head. This body is transgressive down to the north-east in the Beaconsfield-West Arm area, and granophyric dolerite near Deviot suggests differentiation in a dyke-like body, as demonstrated elsewhere in Tasmania (McDougall, in Spry 1962). The Trough structures are probably controlled in part by the Jurassic structure (Sutherland 1966*b*) and by underlying Palaeozoic-Precambrian features.

Ferruginous bauxites are developed on the basement dolerite at Whirlpool Reach, Rosevears, and around Launceston and St. Leonards, underlying Tertiary beds. Carey (1946) regarded the bauxite as remnants of a surface pre-dating the Tamar Trough faulting, but Gill (1962) infers that some, at least, post-date the faulting.

The Tamar Trough has been partly buried by subsequent non-marine sedimentation, interrupted by periods of erosion and lava effusions, and the stratigraphy is summarized in table 1.

LIST OF PLATES

1



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6. Pillow-like lobe of coarse olivine-basalt, overlying and intruding near-vertical Lower Tertiary beds. Foreshore south of Batman Bridge, Whirlpool Reach, East Tamar, looking south.

7. Small fault displacing contact of coarse olivine-basalt overlying Lower Tertiary beds. Foreshore south of Batman Bridge, Whirlpool Reach, East Tamar, looking east.

8. Contorted Lower Tertiary beds below pillowy contact of coarse olivine-basalt. Locality as above.

9. Clastic dyke in coarse olivine-basalt overlying Lower Tertiary beds. Locality as above.

10. Pillowy lobe of coarse olivine-basalt, showing "necking" and a central cavity filled with sediment. Locality as above.

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PRE-VOLCANIC SEDIMENTS

Clays, sands, gravels and boulder beds, with lignitic and lateritic horizons, occupy the length of the Tamar Trough, underlying flows and lacking basalt fragments. Detailed descriptions of these beds in the upper Tamar-Launceston-Evandale areas are given by Johnston (1888) and Longman *et. al.* (1966).

In the lower and middle Tamar, the beds consist of light to dark brown, grey and yellow grits, sands, clayey sands, sandy clays, silty clays and clays, including dense carbonaceous clays and clay pellet horizons. Clays dominate, but some may represent altered feldspathic sandstones, with the original structure being destroyed on compression (Longman *et. al.* 1966, p. 20). These beds are commonly unconsolidated, and outcrops are poor, with exposures mainly restricted to the Tamar foreshores. Fossils include wood, leaf impressions, ramifying tube-like structures suggestive of worm burrows, and disorientated shells of the fresh water mussels *Prohyria johnstoni* and *Alathyria tamarensis* (McMichael 1957), particularly abundant around Spring Bay. Fossils often show ferruginous replacement, and ferruginous horizons with limonitic concretions are common; large entrail-like concretions, to over ten feet across, occur at Ruffins Bay (plate 1), Rocky Point and west Spring Bay.

Interbedded bands of "basalt," up to three feet thick, and down to depths of 250 feet below river level, are logged in some of the Long Reach bores (Maunsell and Partners 1959-1962) suggesting minor eruptions during sedimentation. However, in fact, these may represent passage of the drill through boulders or boulder beds, containing fine grained Jurassic dolerite, stripped off the roof of the intrusion; this was not resolved as the cores in question could not be located. Hughes (1959) records narrow beds of volcanic ash mixed with clays at Whirlpool Reach, but the present author was unable to verify these.

The sediments outcrop to elevations of 150 feet in the lower Tamar, to over 400 feet in the middle Tamar, 600 feet in the upper Tamar, and 800 feet south of Launceston. They are proved to depths below river level of at least 140 feet in the lower Tamar, 300 feet in the middle Tamar, and 270 feet around Launceston (Launceston Marine Board bores; Maunsell and Partners 1959-1962; Longman *et. al.* 1964). This gives a maximum thickness of at least 1,000 feet.

The beds are broadly horizontal, but show regional dips of up to about 10° in from the trough margins. Locally, as a result of later faulting, landslipping and lava flow, they show considerable variations in attitude, ranging from gentle warps forming small dome and basin structures to steep, near vertical drags. Steep, rectangular to rhombic blocky jointing is well developed at a number of places. Small faults cut the sediments at Whirlpool Reach (fig. 7), Deviot (8567E - 2063N), in the underpass above Strathlyn on the West Tamar Highway, and north of Breadalbane (0810E - 8780N; plate 3) where the dislocations reflect in miniature the south-westerly tilting and strike slip faulting of the trough structure of Longman *et. al.* (1964, 1966).

The sediments have been dated palynologically as Palaeocene at Muddy Creek, Palaeocene-Lower Eocene at Launceston and Rose Rivulet, post-Palaeocene/pre-Miocene at Evandale, Eocene at Bell Bay, and Middle Eocene at Spring Bay (Gill 1962; Harris 1968; E. D. Gill pers. comm.).

INTER-VOLCANIC SEDIMENTS

These include similar clays, sands and gravels to the Palaeocene-Eocene beds, but are interbedded with basalts or contain basalt fragments. Precise datings for these sediments are uncertain, but they probably range from post-Upper Eocene to mid-Tertiary ages.

Several bores through basalt at Bell Bay revealed intervening sediments (McLaren and Taylor 1961). This horizon overlies the lower basalt at 80 to 100 feet above river level and consists of sands, carrying basalt pebbles in places.

Dolerite conglomerates at least 50 feet thick, disconformably overlie Middle Eocene beds at elevations of 50 to 500 feet above river level between Hillwood and East Arm, but underlie the flow of coarse basalt. They consist mainly of rounded pebbles and boulders of Jurassic dolerite, to several feet across, in a silty to clayey matrix, and are well exposed in road cuts at the East Tamar Highway-Batman Bridge Road Junction (plate 2). One pebble collected from the conglomerate (8945E - 2312N) in thin section (189) proved to be olivine-basalt, petrologically identical to the lower basalt at Bell Bay. This gives the conglomerates an inter-basaltic age, and they are tentatively correlated with the sediments between the upper and lower flows in the lower Tamar.

Large boulders and blocks of Jurassic dolerite on the east bank of Whirlpool Reach at the Batman Bridge range to over twelve feet across and suggest outcrop. However, bores here passed through into underlying Lower Tertiary beds at depths between five to seventeen feet (Tasmanian Department Public Works 1957; Hughes 1959). Thus, some or all of the dolerite represents an old talus deposit, either mantling an underlying protruding dolerite ridge, or derived from the dolerite on the western bank of Whirlpool Reach. The deposit marks an apparent constriction in the pre-basalt channel of the Tamar through Whirlpool Reach (fig. 6) suggesting that it may pre-date the coarse basalt and be comparable in age with the dolerite conglomerates of the Hillwood-East Arm area.

Inter-volcanic dolerite conglomerates, associated with clays and sands, also underlie basalts in the south Tamar around Rose Rivulet. These beds extend from elevations of 300 to 750 feet, disconformably overlying Palaeocene-Eocene beds and containing rare fragments of weathered basalt. Blake (1959) mapped these as Pliocene boulder beds, but they are probably older, and are tentatively correlated with the dolerite conglomerates in the middle Tamar.

A further inter-volcanic conglomerate may be represented at the base of the coarse basalt in the railway cutting 1¼ miles north of Western Junction Station, but the contacts are not completely exposed. The deposit is at least six feet thick, shows some consolidation and imbrication, and includes worn fragments of basalt, Jurassic dolerite and quartzite, up to boulder size. The basalt fragments in thin sections (194, 576) are petrologically similar to the olivine-basalt east of Rose Rivulet. An underlying position for this conglomerate would indicate that it is younger than the other sub-basaltic conglomerates of the area and that the coarse basalt post-dates the basalt east of Rose Rivulet, with an intervening period of erosion.

Other inter-volcanic horizons may include lateritic horizons developed on olivine-nephelinite, north of Spring Bay in the middle Tamar, and on lower olivine-basalt, above Strathlyn in the upper Tamar, both of which appear to underlie later basalts. Inter-volcanic sediments deposited upstream from earlier basalt flows, or at times of minimum erosion, would lack transported basalt fragments and be difficult to distinguish from the pre-volcanic beds.

POST-VOLCANIC SEDIMENTS

These include siliceous, doleritic and/or basaltic gravels, sands and clays (in some cases not easily distinguished from pre and inter-volcanic deposits), as well as laterites, talus and landslip debris, soils, aeolian sands and alluvium.

Clays and gravels, probably of Upper Tertiary age, were drilled near Perth Railway Station to depths of 50 feet (Jennings 1965). The gravels contain numerous basalt pebbles in many of the horizons and their proximity to the coarse basalt near Perth suggests that the beds post-date the flow and are probably fluviatile deposits of the South Esk. Beds of similar age are exposed in new road cuttings south-east of Perth Bridge, where they disconformably overlie decomposed coarse basalt, with a basal horizon rich in ironstone gravel followed by seven feet of consolidated, friable sands and sandy clays. The beds are gently warped and broken by small north-westerly faults with throws of a few feet.

Widespread deposits of siliceous gravels, sands and clays disconformably overlie basalts in the Tamar Trough (Johnston 1888; Carey 1946; Kershaw 1955, 1958; Green 1959; Blake 1959; Nicolls 1960; McLaren and Taylor 1961; Matthews 1966). These beds are generally unconsolidated, but in Kelso Bay (7350E - 3600N) strongly silicified quartz conglomerate outcrops at river level. Their precise ages are uncertain, but, in the south Tamar (Brickendon Gravels; Nicolls 1960), they are younger than the post-basaltic beds at Perth and are probably late Tertiary or Pleistocene.

Well developed benches are associated with these beds and may relate to old marine stands, with or without tectonic involvement. In the lower Tamar, benches are found at about the 250 feet and 200 feet levels east of Beauty Point, and a prominent and widespread terrace stands between 100 to 150 feet in elevation around Bell Bay, George Town, Lyetta and the south end of West Arm. A possible old shore-line or storm beach deposit at a comparable elevation occurs just north of Beaconsfield (Green 1959) and there is evidence of a former shore-line cut at about 110 feet above M L W S south of Greens Beach (Kershaw 1958). Other benches attributed to marine levels have been recorded at 70-80, 40-50, 25-30, and ten to fifteen feet above sea-level (Green 1959; G. M. Dimmock, K. D. Nicolls, R. C. Kershaw, pers. comm.). Similar levels to these latter ones, on King and Flinders Islands, are probably related to marine levels in the last Interglacial and Post-Glacial periods, while higher levels are probably older than the last Interglacial (Jennings 1959; Kershaw and Sutherland unpubl. ms.) Gravels and clays, up to 75 feet thick, overlie coarse basalt and Tertiary sediments in the Tamar channel at Long Reach to depths of over 140 feet below river level (Maunsell and Partners 1959-1962); these may represent deposits related to lower sea-levels following the last Glacial.

Remnants of lateritic profiles are developed across the basalts, Tertiary sediments, and dolerite of the Tamar Trough; in the south Tamar these represent the Woodstock Surface of Nicolls (1960), regarded as probably Pliocene in age. The profiles form undulating surfaces, reflecting old profiles of the Tamar Valley and sloping from elevations of 990 feet down to 550 feet in the south Tamar and from 450 feet down to 50 feet at the lower Tamar. They tend to be preserved in depressions or fringe slopes on the present land surface. They consist of reddish kraznosems or sandy soils associated with boulders of nodular, pisolitic ferricrete, which may contain fragments of underlying parent rock. Pallid, weathered lower zones in these profiles are seen in basalts 3/4 mile north of Craigburn, about one mile east of Whirlpool Reach, on the plateau south of Atkinson's Creek, and south-east of White Hills. The age of the laterite horizons is uncertain, but where pallid lower zones are developed they resemble the Timboon Terrain in Victoria, dated as Lower Pliocene (Gill 1964). Where ferricretes are only weakly developed or not associated with any marked weathered profiles, as on the post-volcanic siliceous beds and on basalts in the lower Tamar, they may represent semi-lateritisation, such as developed under Pleistocene climatic conditions in Victoria (Gibbons and Gill 1964).

Talus and extensive landslip debris clothe many of the valley slopes in the area. These include pebbles shed from dolerite gravels, extensive float derived from basalt cappings, gravel and sand shed from post-basaltic siliceous deposits, ferricrete fragments and "buck shot" ironstone gravels derived from lateritic profiles, and deep soils developed on Lower Tertiary beds. Basaltic float is particularly extensive around Bell Bay, Beauty Point, north of Hillwood, Craigburn, Deviot, Spring Bay, Moriarty Reach, Long Reach, East Arm, Brady's Lookout, Gaunt's Hill, Atkinson's Creek, Muddy Creek, and Rose Rivulet, and was discussed under landslip features. Huge toppled blocks to over 50 feet high and hundreds of feet across (plate 5) are mapped as solid masses, north of Craigburn. Many of the slides, associated with talus, were presumably initiated by active channel cutting and erosion by the Tamar drainage following sea-level fall in the last Glacial period, and movements are still current. Ferruginous cementation of talus is seen in road cuts in the West Tamar Highway south of Atkinson's Creek (9165E - 0844N) and west of Brady's Lookout (9010E - 0971N); this suggests that these deposits are older than the typically uncemented talus and are probably pre-Holocene or even pre-Pleistocene.

Late Quaternary windblown siliceous sands are developed at the Tamar Heads, where littoral sands extend over older post-basaltic deposits as far south as Bell Bay, and also occur inland in the south Tamar (Nicolls 1960). Recent coastal calcareous sands form stabilised dunes and beach ridges around the Tamar mouth. The alluvium of the present Tamar drainage includes gravel and sand deposits, seen in the slip-off slope at Native Point, in the spit at Swan Point, and in pebbly and sandy beaches, and there are extensive tidal mud flats and flood plains. The terrace systems associated with the drainage in the south Tamar are discussed in detail by Nicolls (1960).

VOLCANIC ROCKS

These are dominantly basaltic and alkaline lavas, with rare pyroclastic deposits. Stratigraphical relationships indicate that the volcanism commenced in post-Eocene and continued into at least mid-Tertiary time. The eruptive vents are not obviously exposed, but a number can be recognised or inferred from field criteria such as listed by Burns (1964), from detailed petrology, or from gravity anomalies. The lavas erupted from about a dozen centres spread along the Trough, mainly on fault lines, and relationships of detected centres to the structures of the Tamar Trough are shown in fig. 1. A cluster of centres in the Deviot-East Arm area is associated with intersecting faults and an apparent change in structure from a fault wedge to a possible graben.

The lavas are mostly undersaturated to nearsaturated alkali olivine-basalts, with minor tholeiitic olivine-basalt, and alkaline rocks include nepheline-basanite, limburgite and olivine-nephelinite (Sutherland 1969*b*). They occur in four main areas (fig. 2, table 1), discussed in detail separately.

Fig. 2. Distribution of the Tertiary Volcanic rocks of the Tamar Trough.

Fig. 3. Geological Map and sections, Lower Tamar area.

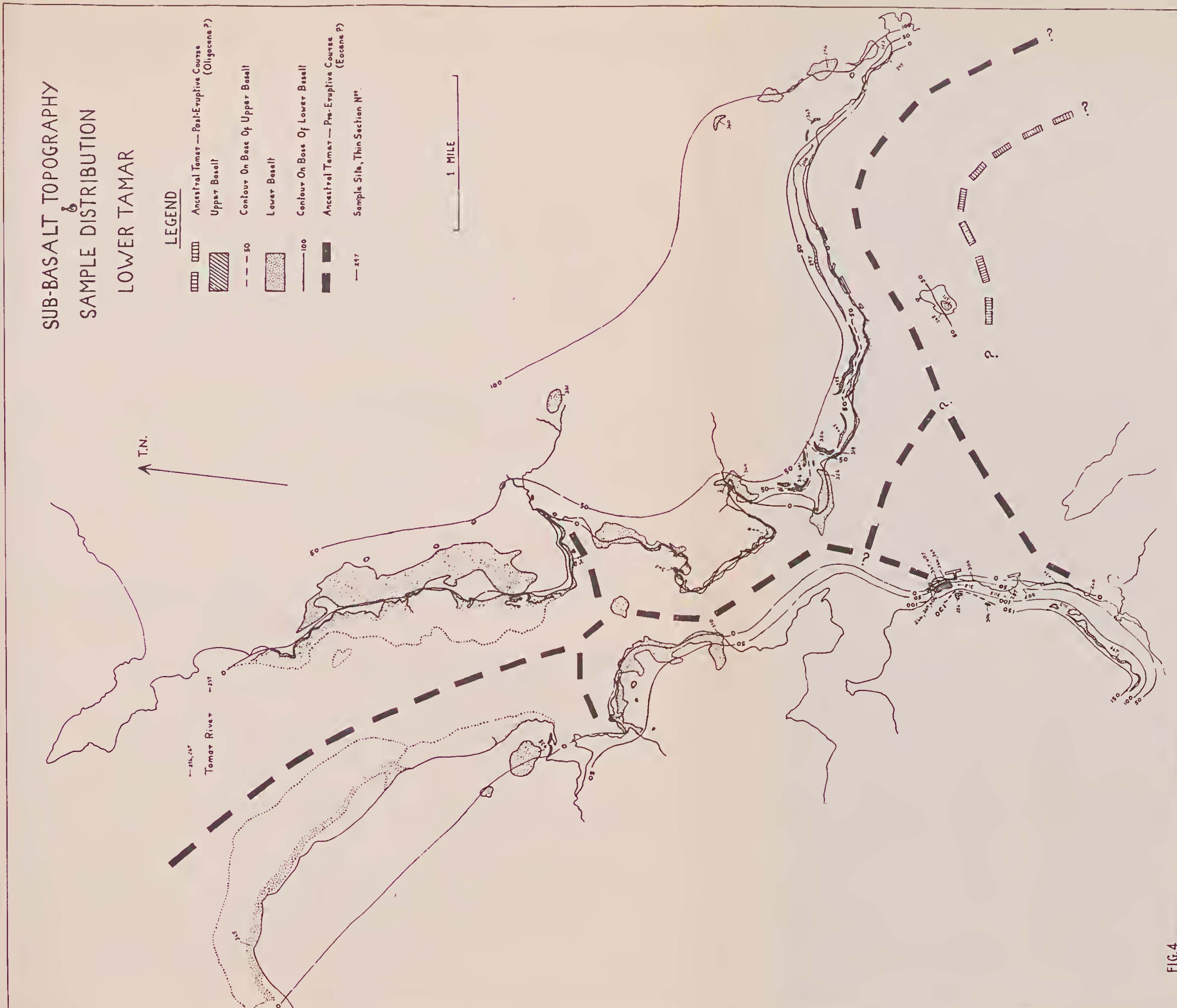

Fig. 4. Map of basal contours on basalt, Lower Tamar area.

LOWER TAMAR

Two basalt flows outcrop in the area (figs. 3 and 4), separated by an interval of erosion and sedimentation (McLaren and Taylor 1961).

LOWER OLIVINE-BASALT

This basalt fills a channel following a similar course to the present Tamar (fig. 4). A small steep tributary valley side at Inspection Head wharf was straddled by Launceston Marine Board bores; Bore 1 drilled underlying Tertiary sediments to 70 feet below Astronomical Low Tide, and Bore 2 drilled basalt to 59 feet below A.L.T., without passing through. Similarly, bores at Garden Island and Barrel Rock intersected basalt to 42+ feet below A.L.T., but basalt overlies sediments at many points along the Tamar shores. Inland, the base rises to elevations of 150 feet giving a maximum basalt thickness of 210+ feet and an average cross-sectional slope of one in thirteen for the pre-basalt Tamar valley, but steepening greatly along the main channel.

The basalt is massive, with strong, irregular and rectangular jointing and shows cooling columns around Point Effingham, Georgetown, Lyetta, Greens Beach and Low Head. Joint planes in bores at Bell Bay show polishing indicating slight movement and some contain pyrite (McLaren and Taylor 1961). When fresh, the basalt is dense, even grained and darkish blue-grey rock, with sporadic amygdales containing carbonates. It decomposes to soft blue or brown clay on the surface, with erratic weathering extending to varying depths. The base is slightly scoriaceous and weathered at contacts, and baking of underlying sediments generally extends for a few inches and rarely for two to three feet.

Petrology

Thin sections (30 slides, fig. 4) show corroded olivine phenocrysts in a groundmass of plagioclase, pyroxene, olivine and iron ore, with intersitial carbonate, chlorite, serpentine, zeolite, glass, opal and chalcedony (plate 1, Sutherland 1969*b*).

Olivine (12-17%; 2.5 mm. max. size; $2V_z 88-96^\circ \approx Fo_{91-76}$) is partly altered to limonite, serpentine or carbonate. Plagioclase (38-49%) forms zoned labradorite laths ($\approx Ab_{40-50}$; to 1 mm. long, sometimes flow aligned) passing into intersertal sodic plagioclase. Colourless augite (24-27%; $Z:c 44-46^\circ$) is intergranular, mostly less than 0.2 mm., but to 1.2 mm. across in rare pyroxene aggregates (368). Iron ore (6-11%, to 0.5 mm.) occurs as elongate laths, irregular intersertal masses and squarish grains. Small apatite needles are common in the intersertal plagioclase and some colourless glass may be present (343, 365).

Late interstitial and amygdaloidal material (up to 20%) is predominantly carbonate (319, 341, 342, 345, 366, 370), or serpentinitic, nontronitic and chloritic clay (257, 294, 297, 299, 303, 340, 344, 369), or both (261, 326); rarely it is zeolite, with properties resembling chabazite (256, 267). Green opal is present in some sections, sometimes with greenish or blackish chalcedony (294, 295, 340, 345, 367, 368). Sporadic larger ovoid amygdales generally contain clay or carbonate. Rare small xenoliths (368) are composed of anhedral quartz and carbonate, bordered by a corona of colourless augite prisms to 0.7 mm. long.

The rock is a nearsaturated alkali olivine-basalt, (Analysis 1, table 1, Sutherland, 1969*b*).

Source and Age

The source is problematical. A couple of north-westerly trending decomposed dykes, with silicified and pyritised contact zones, cut Permian strata on West Arm, between Boatscrew and Soldiers Points. These dykes may have fed the flow, but the lack of basalt in the immediate vicinity, with intrusive Jurassic dolerite nearby at Anchor Point, suggests that they more probably relate to the dolerite. It is possible the source was located in the middle Tamar near East Arm, where pebbles of identical basalt in sub-basaltic gravels suggest its original extension into this area.

The basalt was erupted following dissection of the underlying Eocene beds. This disconformity probably correlates with the Middle-Upper Eocene disconformity in similar beds in Bass Strait and south-western Victoria (Bock and Glenie 1965; Esso Exploration Australia Inc. 1966). No soil of any magnitude was observed developed on the sediments immediately below the basalt in exposures, or in bore cores (E. D. Gill pers. comm.). This infers that the basalt is not much older than the dissection of the sediments, and is probably Upper Eocene in age, or younger.

A Lower Tertiary age for the basalt is also indicated in the middle Tamar. Here, the gravels with pebbles apparently derived from the flow, as well as a basalt remnant correlated with the upper flow in the lower Tamar, are disconformably overlain by coarse basalt of probable Upper Oligocene or Miocene age.

UPPER OLIVINE-BASALT

This basalt resembles the lower basalt in the field, but outcrops less extensively and shows some petrological differences in thin sections. In the Bell Bay-Point Effingham area it overlies the lower flow and inter-basaltic sediments at elevations between 80-100 feet and is at least fifteen feet thick. At Inspection Head it appears to overlie the lower basalt at an elevation of 50-70 feet and outcrop inland to elevations of about 100 feet. Similar basalt is found between the Inspection Head and Beauty Point wharves at river level, with no evidence of the lower basalt, but this is a zone of major landsliding, and large scale downward movements may be involved rather than a channel filling.

Petrology

In thin sections (15 slides, fig. 4) the upper basalt resembles the lower basalt, but the olivine ($2V_z 88-98^0 \approx Fo_{91-72}$) is mostly unaltered and a darkish mesostasis replaces the interstitial feldspar, carbonate and clay. The mesostasis contains skeletal crystallites and acicular sheaves of augite, plagioclase crystallites and long slender laths of iron ore, and may be quite dark with globules of iron ore. The augite margins tend to faint mauve tints, particularly in the mesostasis, and are probably slightly titaniferous. Most sections show some brownish green opal and chalcedony, sometimes with carbonate.

Minerals lining amygdales and veinlets in the rock above Inspection Head include chabazite, apophyllite, phillipsite, calcite, siderite, and rare natrolite.

The rock is a nearsaturated alkali olivine-basalt with a fairly high iron oxide content (Analysis 2, table 1, Sutherland 1969*b*), and the excess iron ore presumably gives the dark mesostasis.

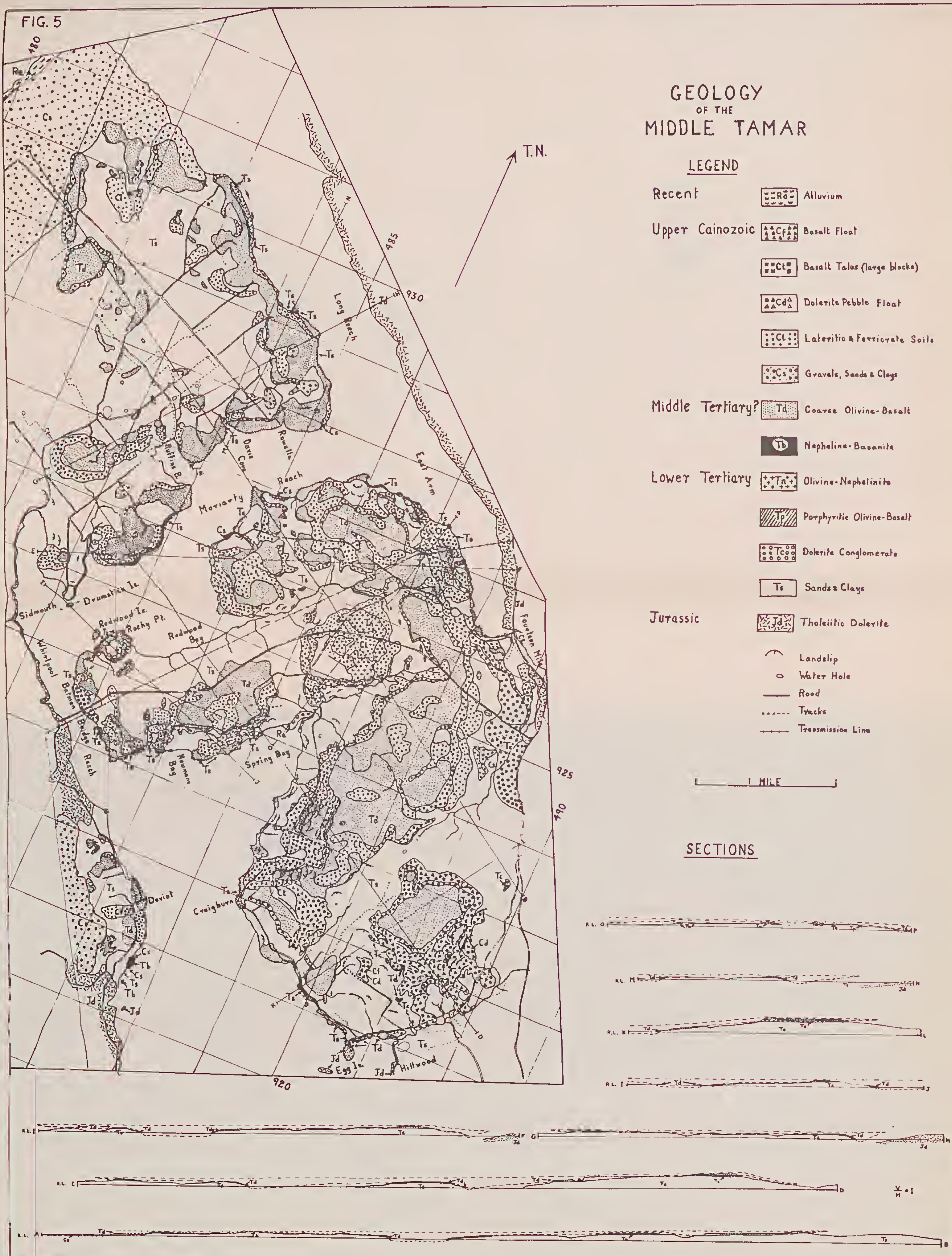

Fig. 5. Geological map and sections, Middle Tamar area.

Fig. 6. Map of basal contours on basalt, Middle Tamar area.

Source and Age

The basalt is correlated with a porphyritic variety of similar basalt at East Arm in the middle Tamar, suggesting eruption from a plug in that locality. The basalt disconformably overlies the lower flow (post- Eocene?) and inter-basaltic sediments, and its porphyritic correlate is disconformably overlain by coarse basalt of probable Upper Oligocene or Miocene age. This suggests a probable post- Eocene or Oligocene age.

The eruption of lavas into the lower Tamar by the Lower Tertiary may have diverted the Tamar out of its valley, just north of Beaconsfield, into the wide valley between West Head and Badger Head. Gaps in bedrock outcrop, and Tertiary sand and gravel deposits (dipping at over 30° N.E., two miles S.W. of Beaconsfield; Green 1959), along this line may mark an old channel, but detailed stratigraphical and geomorphological work is required to prove this. There is certainly a pronounced westward swing in the old Tamar course, preserved by the younger coarse basalt, at the north end of Long Reach in the middle Tamar (fig. 6). Rediversion of the Tamar from such a course to its present one could have resulted from out pouring of this later lava, or from later downstream breaching of the basalt barrier.

MIDDLE TAMAR

Extensive lava disconformably overlies Lower Tertiary sediments in the middle Tamar (figs. 5 and 6). Four distinctive types are recognised.

PORPHYRITIC OLIVINE-BASALT

This forms a small outcrop at East Arm (8700E - 2700N) at about 250 feet elevation, below the coarse basalt capping the hill. The exposure dips north, with cooling columns dipping south at about 45°, and either represents a remnant of a valley fill or a plug.

Petrology

Thin sections (five slides, fig. 6) show glomeroporphyritic and microporphyritic olivine, plagioclase and augite in a groundmass of plagioclase, augite, olivine and iron ore, interspersed with darkish mesostasis (plate 2, Sutherland 1969*b*).

Olivine (6-13%; 4 mm. max.; $2V_z 88-101^\circ \approx Fo_{90-64}$) is corroded but fresh, and plagioclase (29-38%; 2.5 mm. max.) is zoned labradorite ($\approx Ab_{40-54}$). Pale brown augite (26-31%; 1.5 mm. max., mostly 0.1-0.5 mm.; $2V_z 58^\circ$, z:c45-46°) tends to form separate aggregates or clusters around olivine and plagioclase. The mesostasis (up to 21%) closely resembles that described in the upper olivine-basalt, Lower Tamar, and contains occasional zeolite cores. In most slides the phenocrysts tend to grade into the groundmass, except from near the basalt contact (325) which shows a much finer grained and distinct groundmass.

The rock is a near saturated alkali olivine-basalt (Analysis 3, table 1, Sutherland 1969*b*). It resembles a porphyritic variety of the upper olivine-basalt in the lower Tamar, and shows higher alumina, lime and soda, and lower magnesia and iron oxide; this presumably reflects the greater plagioclase content of the rock.

Source and Age

The texture of the rock suggests relatively slow cooling near or within a vent. It disconformably overlies Lower Tertiary beds and is disconformably overlain by coarse basalt of probable Upper Oligocene-Miocene age. It is tentatively correlated with the upper olivine-basalt flow downstream in the lower Tamar.

OLIVINE-NEPHELINITE

A small flow of olivine-nephelinite outcrops north-east of Spring Bay at elevations of between 100 to 200 feet. It is up to 50 feet thick and fills a small south trending valley cut in Lower Tertiary sediments. The rock is dense, contains small peridotite xenoliths up to three inchhes across, and is strongly weathered to reddish lateritic kraznosem soils. A coarse pegmatitic variety is developed at 8609E - 2550N.

Petrology

Thin sections (eleven slides, fig. 6) show sporadic peridotite xenoliths amongst olivine, augite, iron ore and apatite, set in a feldspathoidal groundmass (plate 3, Sutherland 1969*b*).

The peridotite xenoliths consist mostly of coarse allotriomorphic olivine ($2V_z 86\text{-}96^\circ \approx Fo_{94-76}$; mostly $2V_z 88\text{-}92^\circ$, $\beta 1.667\text{-}1.678 \pm 0.002$, $\approx Fo_{91-86}$), with some colourless clino-pyroxene ($2V_z 67^\circ$, Z:c50°, $\beta 1.690\text{-}1.692 \pm 0.002$), ortho-pyroxene (sometimes resorbed or with exsolved clino-pyroxene), calcic plagioclase ($\approx Ab_{10}$) and greenish-brown spinel. There are rare xenocrysts of clino-pyroxene, mantled with titan-augite (228), and rare zoned feldspars (272). Accidental xenoliths of fused feldspathic sediment(?) are partially or completely replaced with ingrown prismatic augite (271, 272, 282, 286, 315).

Olivine (12-21%) in the rock includes crystals with strain polarisation and translation lamellae, probably derived from the peridotite xenoliths. Truly phenocrystic, euhedral olivine ($2V_z 92\text{-}98^\circ \approx Fo_{84-72}$) is mostly less than 1 mm. in size. Pale mauve, zoned, pleochroic titan-augite (29-41%, Z:c$45\text{-}58^\circ$) forms small prisms and rosettes, rarely exceeding 0.5 mm. Iron ore (5-9%) occurs in squarish to irregular grains and aggregates (0.6 mm. max., mostly to 0.2 mm.), and apatite (2-5%) forms coarse to slender prisms (1.5 mm. max.).

The mesostasis varies from a hyalopilitic colourless to cloudy glass to a groundmass of nepheline (up to 25%), alkali feldspar (up to 15%), and a microlitic mesostasis containing acicular crystallites and some indeterminate chloritic(?) material. It is extremely fine-grained in some sections (272, 286, 315) with uneven cloudy dustings of iron ore, but in others (228, 271, 273) it forms poikilitic potassic nepheline (to 2.5 mm.) and a strongly zoned interstitial potassic feldspar (orthoclase?, to 1.5 mm.). Minor zeolites include stilbite and phillipsite (?) and ovoid amygdales to 1 mm. across include analcime(?) and clay. A late-stage vein, 2 mm. wide with diffuse margins (277), contains numerous biotite flakes (to 0.5 mm.), some prismatic, strongly pleochroic titan-augite, and acicular apatite, in a fine grained nepheline-glass base.

Pegmatitic nephelinite

The coarse pegmatitic variety lacks olivine and contains titan-augite and nepheline (6 mm. max.) in graphic to arborescent intergrowths, with an abundant microlitic mesostasis (plate 4, Sutherland 1969*b*).

The titan-augite is strongly colour zoned (X mauve, Y reddish-mauve, Z yellow-brown, Y>X≃Z; $2V_z 41^\circ_{core} \text{---} 70^\circ_{rim}$, $Z{:}c38\text{-}48^\circ_{core} \text{---} 48\text{-}56^\circ_{rim}$, some paler edged crystals with $Z{:}c52^\circ_{core} \text{---} 46^\circ_{rim}$). Some grades or alters marginally to aegirine-augite ($Z{:}a46^\circ_{core} \text{---} 18^\circ_{rim}$). Squarish, skeletal and lath-like crystals of ilmenite or titano-magnetite (to 1.2 mm.) are largely altered to leucoxene.

The mesostasis consists of crystallites and radiating sheaves of zoned alkali feldspar laths (to 4 mm.), some acicular aegirine-augite, apatite, chloritic(?) material and zeolites. Amygdales, up to 2 mm. across, include analcime, radiating fibrous zeolite (gonnardite?), stilbite and phillipsite(?).

The olivine-nephelinite is a strongly under saturated alkaline rock (Analysis 16, table 1, Sutherland 1969*b*); the pegmatitic nephelinite presumably increases in silica, soda and potash, and decreases in magnesia.

Source and Age

The pegmatitic nephelinite may mark the approximate position of the vent for the flow; such phases are found in probable vents elsewhere in Tasmania, as at Shannon Tier (Edwards 1950) and at Scottsdale (Marshall *et. al.* 1965).

The flow post-dates dissection of the Middle Eocene sediments and probably also post-dates the nearby inter-volcanic gravels, as these lack any fragments of the rock. Its lateritised surface appears to extend below the base of the adjacent coarse basalt of probable Upper Oligocene-Miocene age, suggesting an older residual and a probable Oligocene or early Miocene age.

NEPHELINE-BASANITE

Outcrop of this rock is confined to the shore, ½ mile south of Deviot Yacht Club, where it overlies Lower Tertiary sediments. It is massive, at least ten feet thick, with a fine grained amygdaloidal margin grading into coarser rock, and contains rare small peridotite xenoliths.

Petrology

Thin sections of the fine grained rock (392, 583, 584, 586) show olivine phenocrysts in a ground mass of plagioclase, augite, some olivine, iron ore, apatite and a feldspathoidal zeolitic mesostasis (plate 5 Sutherland 1969*b*).

Olivine (18-20%; 2.2 mm. max., mostly to 0.5 mm.; $2V_z 87\text{-}102^\circ \approx Fo_{92-62}$) is slightly altered to serpentine, and includes some interlocking grains showing translation lamellae. Rare corroded augite phenocrysts (to 2 mm.; $2V_z 55\text{-}65^\circ_{core} \text{---} 49\text{-}52^\circ_{rim}$, $Z{:}c37^\circ_{core} \text{---} 44^\circ_{rim}$) are overgrown with titan-augite, similar to that of the intergranular groundmass grains (27-30%; 0.6 mm. max., mostly to 0.2 mm.). Labradorite (22-29%) forms laths and zoned anhedral plates (to 1 mm., 0.6 mm. av.) Idiomorphic and skeletal iron ore (7%, to 0.8 mm.) moulds and encloses groundmass grains. Apatite is prominent as coarse prisms (to 0.8 mm.) and small needles in the mesostasis. The base is a clear glass containing nepheline (up to 8%), analcime and other zeolites, and scattered biotite flakes. Numerous round amygdales (0.2 - 2 mm.) contain stilbite(?) and other zeolites.

Thin sections of the coarser phase (390, 393, 585) show a coarse olivine-basalt containing olivine (25%; $2V_z 92\text{-}102^\circ$-Fo_{84-62}), with a sub-ophitic to ophitic intergrowth of titan-augite, plagioclase and iron ore, and a microlitic mesostasis. The titan-augite (2.5 mm. max.; $2V_z 71_{core}$—77°_{rim}, Z:c $48\text{-}54^\circ_{core}$—$48\text{-}65^\circ_{rim}$) is strongly colour zoned, sometimes showing deeper coloured cores and sometimes deeper coloured margins. The labradorite (1.8 mm. max.) is zoned from about Ab_{37} to more sodic compositions and is mantled with alkali feldspar. The mesostasis consists of small laths and curved to spherulitic microlites of alkali feldspar, apatite prisms, grains and crystallites of iron ore, biotite flakes and a zeolitic base containing analcime, spherules of radiating zeolite and little or no apparent nepheline.

Analyses of the fine and coarse phases of the rock (analyses 14 and 15, table 1, Sutherland 1969*b*) are similar, but the coarse phase is slightly richer in silica and poorer in soda, which probably accounts for the disappearance of modal nepheline.

Source and Age

The outcrop suggests a small extrusion with a nearby source, possibly about the small exposure of coarse rock at low tide level, near apparent intersection of faults.

The rock post-dates dissection of underlying Lower Tertiary sediments. Its precise age is uncertain, although it appears to underlie the nearby outcrops of coarse basalt of probable Upper Oligocene-Miocene age.

COARSE OLIVINE-BASALT

This basalt outcrops extensively to elevations of about 600 feet, forming cliffs a hundred feet high north of Craigburn, and drilling has proved it to at least 99 feet below mean river level (Maunsell and Partners 1959-1962). Contours on the base (figs. 5 and 6) give pre-basalt valley sides sloping from about one in ten to about one in two or steeper along the central channel, and a maximum basalt thickness around 400 feet. There is no positive evidence for multiple flows or any significant faulting of the basalt, but poor exposures and blanketing by talus and landslips obscure detailed relationships between outcrops. Sedimentary horizons in the basalt in the bores at Long Reach (Maunsell and Partners 1959-1962), and Whirlpool Reach (Tasmanian Department of Public Works 1957) can be accounted for by landslip movements, clastic dykes and intricate partly intrusive contacts, as detailed later. Petrological variations observed in thin sections are all reconcilable with possible natural variation, including differentiation, within a thick flow.

The basalt is generally massive, medium grained and bluish-grey when fresh, but is strongly weathered and decomposed in some exposures and contact zones. Chilled contacts are generally absent and a relatively large grain size is commonly maintained up to the contact. Irregular patches and veins of coarse pegmatites cut the rocks at Long Reach, Rowella, East Arm, and on the plateau above Craigburn (fig. 6, plate 4). Peridotite xenoliths are present along the western shore of East Arm.

There are sporadic veins, patches and amygdales carrying deuteric and secondary minerals. Amygdales exposed in the quarry, ½ mile north of Craigburn, range to three inches across and release watery fluid when broken open. Most contain either chabazite, or translucent, botryoidal, fibrous linings of thomsonite, sprinkled with small radiating spherules

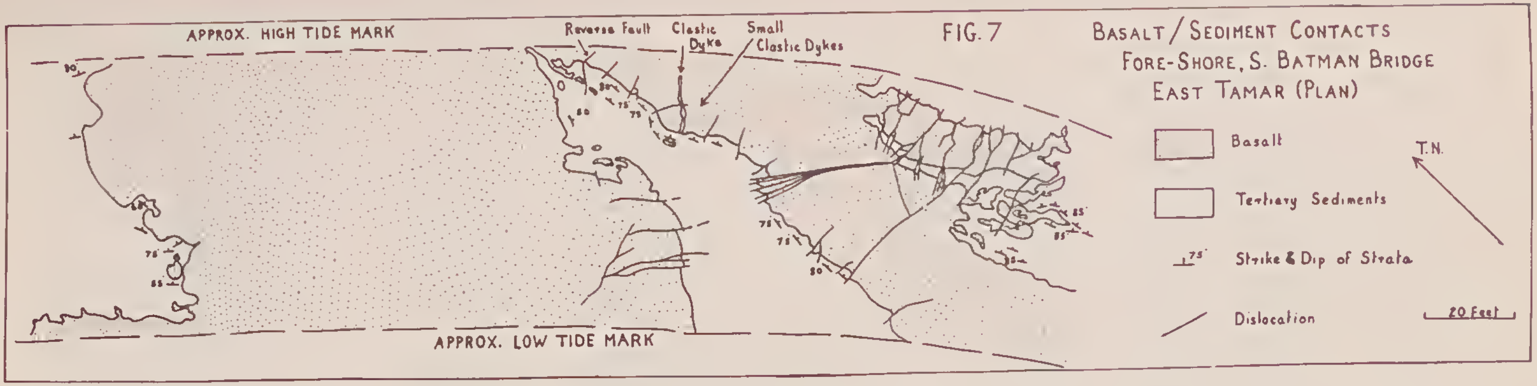

Fig. 7. Diagram of basalt-sediment contacts, Whirlpool Reach.

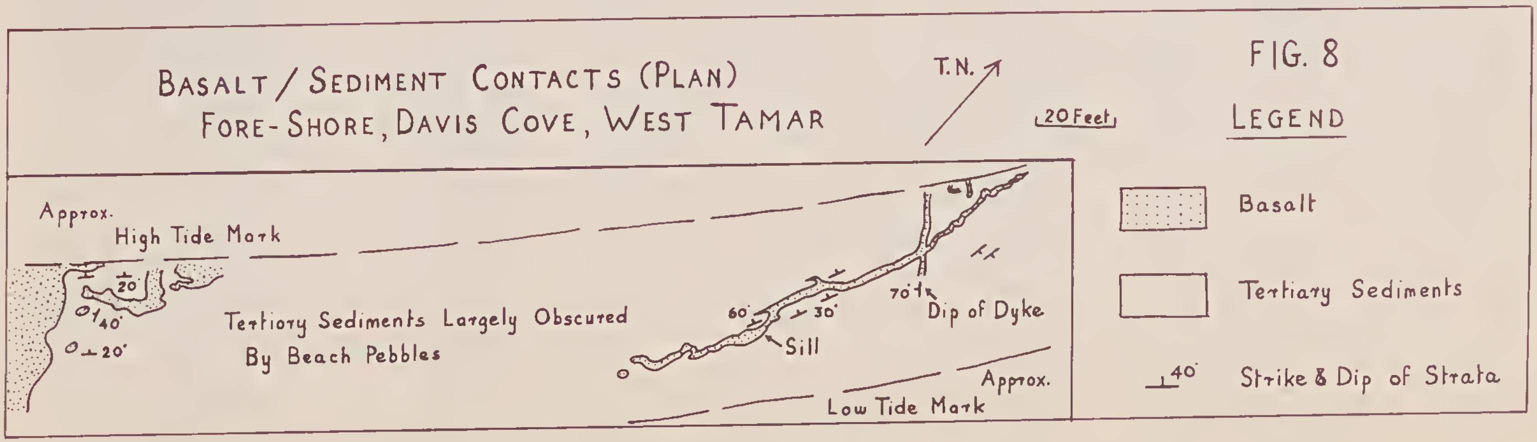

Fig. 8. Diagram of basalt-sediment contacts, Davis Cove, Moriarty Reach.

of gyrolite, and there is rarer apophyllite and calcite. Spherules and linings of zoned radiating zeolite (scolecite, thomsonite and gonnardite?) are common in amygdales in the basalt elsewhere.

Close, platy jointing is developed near basalt contacts at East Arm (8422E - 2756N), Moriarty Reach (8467E - 2631N), Long Reach (8330E - 3011N) and Whirlpool Reach (8441E - 2303N), and passes up into blocky rectangular and irregular jointing. Blocky jointing commonly develops both normal and parallel to the basalt base, and is inclined in dipping contacts on the Batman Bridge Road (8663E - 2660N), Redwood and Drumstick Islands, and on Rowella shore. Close, vertical jointing on the top of the basalt capping north of Hillwood (fig. 6) is interpreted as a remnant of the upper zone of the flow. Polygonal cooling columns occur in a number of places and north of Craigburn (8700E - 2325N) they form inverted fan structure. Small north-westerly and westerly trending fractures dislocate the basalt on the shore south of Batman Bridge, with movements of up to about a foot (fig. 7; plate 7).

Baking at basalt contacts is generally slight, but along the central channel clays may be baked and blackened up to a couple of feet from contacts. Small prismatic cooling columns up to six inches long occur in baked buchitic clay at Long Reach (8345E - 2980N), and minor chert hornfels occur at East Arm (8800E - 2624N) and Moriarty Reach (8395E - 2744N).

Steep contacts exposed on the Tamar shores are often extremely irregular. Pillow-like lobes, dykes and a thin sill, with baking on both contacts and irregular flame-like structures, break the sediments on the shore at Davis Cove (fig. 8). The basalt in these bodies is decomposed and scoriaceous, with more coarsely scoriaceous interior zones, and the enclosing sediments show steep dips suggesting concomitant tilting or slumping. Numerous pillow-like structures are exposed on contacts along the shore south of Batman Bridge (fig. 7), associated with contorted and near vertical sediments (plates 6 and 8). These include near isolated "pillows" showing necking and sometimes small secondary lobes (plates 6 and 10). Irregular contacts also occur along Long Reach (8425E - 2923N; 8299E - 3045N) and Spring Bay (8545E - 3342N). These intrusive bodies are not necessarily feeders themselves, but may be merely localised intrusion from the passage of lava over unconsolidated and water-saturated sediments.

Thin, clastic veins of friable sandstone, up to six inches wide, cut the basalt and infill cores in some of the "pillow" bodies on the shore south of Batman Bridge (plates 9 and 10); the derivation of the sediment is not clear in these exposures. Similar clastic veins associated with part-intrusive contacts at Spring Bay (8545E - 2342N) appear to have intruded up from the underlying sediments.

Petrology

In thin sections (63 slides; fig. 6) the basalt is generally medium grained, with some coarse grained pegmatites, but in a few sections from near contacts it grades into fine grained rock. The basalt contains olivine, plagioclase, augite, iron ore and apatite, with a feldspathic and zeolitic mesostasis. Textures range from porphyritic and intergranular to subophitic and intersertal (plates 6 and 7, Sutherland 1969*b*). Peridotite xenoliths in the basalt at East Arm (199) consist mainly of coarse interlocking olivine ($2V_z 86\text{-}96^\circ \approx Fo_{94-76}$; mostly $2V_z 88\text{-}92^\circ$, $\beta 1.669\text{-}1.678 \pm 0.002$, $\approx Fo_{91-86}$) with strain polarisation and translation lamellae, and some partly resorbed clino-pyroxene ($2V_z 53^\circ$, $Z{:}c 46^\circ$, $\beta 1.688\text{-}1.690 \pm 0.002$).

Corroded olivine (4 mm. max., $2V_z 86\text{-}102^\circ$-Fo_{94-62}) forms 9-35% of the basalts, with olivine rich varieties grading to picrites, but the majority of slides carry 15-25% olivine. It is glomeroporphyritic in sections with intergranular groundmass, but this is masked in sections with coarser sub-ophitic to ophitic fabric. It shows some alteration to serpentine, or "bowlingite," and may include iron ore. Larger crystals commonly show translation lamellae and are probably derived from disaggregation of peridotite xenoliths.

Augite (24-38%) forms colourless, glomeroporphyritic, corrosion riddled crystals ($2V_z 53^\circ$, $Z{:}c 48^\circ$) in some slides (168, 169, 192, 193, 223, 224, 230, 330), but generally it is titan-augite forming intergranular prisms and grains (to 0.5 mm.) or subophitic to ophitic plates (to 3 mm.). The titan-augite (X mauve, Y reddish-mauve, Z fawn, Y>X>Z) shows weak to marked colour zoning and pleochroism. Colours are mostly stronger in outer zones and are most marked in sections with coarse sub-ophitic to ophitic textures, or, if intergranular, in association with an abundant microlitic mesostasis. There is considerable variation in optic axial and longitudinal extinction angles, and numerous measurements generally showed increase in $2V_z$ and Z:c from crystal cores to rims. Small pale intergranular grains gave $2V_z 73\text{-}78^\circ$ and $Z{:}c 42\text{-}52^\circ_{core} \longrightarrow 48\text{-}55^\circ_{rim}$; small to medium sized grains with moderate to deep colour gave $2V_z 50\text{-}57^\circ_{core} \longrightarrow 58\text{-}71^\circ_{rim}$ and $Z{:}c 39\text{-}47^\circ_{core} \longrightarrow 45\text{-}61^\circ_{rim}$; and large plates with moderate to deep colour gave $2V_z 54\text{-}67^\circ_{core} \longrightarrow 62\text{-}71^\circ_{rim}$ and $Z{:}c 42\text{-}55^\circ_{core} \longrightarrow 46\text{-}60^\circ_{rim}$. The titan-augite may grade or alter marginally to aegirine-augite, particularly in contact with the mesostasis.

Laths and plates of labradorite (20-48%; 4 mm. max.) are zoned from about Ab_{38} to Ab_{50}. Iron ore (6-11%; titano-magnetite or ilmenite, commonly altered to leucoxene) forms skeletal crystals, irregular masses and laths (to 1 mm.). Apatite (2-4%) is present as coarse prisms (to 0.7 mm.).

The mesostasis forms up to 32% of the rocks and four gradational types are distinguished. Mesostasis type 1 (15 slides) consists of intersertal sodic plagioclase containing small prisms and crystallites of titan-augite (commonly altered to soda-pyroxene), biotite flakes, apatite needles, grains and globules of iron ore, some zeolite and clear glass. Mesostasis type 2 (26 slides) is similar, but interstitial zeolites predominate, may become particularly abundant (168, 169, 223, 232, 330, 396), and include analcime, potash analcime, and fibrous radiating zeolites. In sections with this mesostasis iron ore tends to be idiomorphic and separated from it, and titan-augite, if intergranular, shows only faint colour and pleochroism.

Mesostasis type 3 (19 slides) consists of numerous small laths and curved to spherulitic microlites of alkali feldspar, apatite prisms, grains and crystallites of iron ore, biotite flakes and a zeolitic, analcime-rich base with greenish indeterminate chloritic(?) material. It is abundant in some sections (170, 184, 220, 237, 250, 252, 289, 292, 413) where it contains skeletal titan-augite and prominent thin laths of iron ore. Mesostasis type 4 (3 slides) resembles type 3, but lacks the greenish material and grades into type 2. Mesostasis types 3 and 4 invariably associate with deeply coloured titan-augite.

The distribution of mesostasis type, in association with groundmass texture in the rocks (fig. 6), shows no consistent pattern, although mesostasis type 3 tends to prevail in the lower profiles, within the main basalt channel.

The coarse basalt ranges from under saturated to near saturated alkaline compositions (analysis 4-6, table 1, Sutherland 1969*b*). The picritic type (analysis 5) is richer in magnesia and poorer in silica and alumina compared with the more feldspathic and mesostasis-rich types (analysis 4 and 6). Extreme types of the basalt include porphyritic and pegmatitic varieties described below.

Porphyritic olivine-basalts: Basalt from Spring Bay (8544E- 2341N) in section (171) shows phenocrysts of olivine and plagioclase (2 mm. max.) grading into a fine grained groundmass of plagioclase, pale augite, iron ore, apatite and zeolite. The plagioclase is zoned from labradorite to andesine and subophitically intergrows and poikilitically encloses groundmass minerals. Small scattered inclusions of sediment (?) are replaced with minute clino-pyroxene grains, with apparent corona structure.

The texture suggests chilling of the rock as normal crystallisation was proceeding. The rock is from a part-intrusive contact of the coarse basalt, and this suggests quick cooling where a lava tongue entered the underlying, probably wet, sediments.

Pegmatitic veins: A pegmatitic vein, in coarse picritic basalt from East Arm shore, in sections (197, 198) shows irregular margins up to 7 mm. wide bordering the interior of the vein. The margins are composed of stout zoned labradorite crystals that include apatite and ophitically intergrow with titan-augite, skeletal iron ore and olivine. The titan-augite is strongly colour zoned ($2V_z 67\text{-}74^{\circ}_{core} \text{—} 74\text{-}84^{\circ}_{rim}$, Z:c $35\text{-}51^{\circ}_{core} \text{—} 43\text{-}66^{\circ}_{rim}$). Olivine ($2V_z 100\text{-}105^{\circ}$ Fo_{65-55}) is sparse, more fayalitic than in the host rock, and tends to be altered to "bowlingite" and replaced marginally by iron ore. Small amounts of mesostasis (type 2) are present. The minerals (to 2.5 mm. long) show slight alignment normal to the vein margins. The interior of the vein is up to 12 mm. wide and is largely mesostasis (types 3 and 4) containing sporadic smaller crystals of the margin minerals.

Pegmatitic basalts: These form patches to over eight feet across in the coarse basalt. Thin sections (191, 328, 409, 658) from pegmatite above Craigburn (8767E - 2435N) and on Long Reach shore show coarse ophitic and dendritic intergrowths of plagioclase, titan-augite, olivine and iron ore, with an analcime-rich mesostasis (plate 8 Sutherland 1969*b*).

Olivine (10%; 7 mm. max.; $2V_z 100\text{-}105^{\circ}$-$Fo_{65-55}$) forms late intergrowths to deeply corroded crystals rimmed with iron ore. Labradorite in laths and plates (36%; 9 mm. max.) is zoned from about Ab_{38} to more sodic compositions and is overgrown with alkali feldspar (up to 16%). The overgrowths are mostly less than 0.5 mm. wide and are riddled with inclusions and graphic intergrowths of pyroxene, iron ore and apatite. Large plates of titan-augite (21%; $2V_z 65\text{-}71^{\circ}_{core} \text{—} 67\text{-}79^{\circ}_{rim}$, Z:c $33\text{-}62^{\circ}_{core} \text{—} 38\text{-}64^{\circ}_{rim}$) are strongly colour zoned, mostly with deeper coloured outer zones, but sometimes with paler margins. Aegirine-augite is a common marginal alteration on titan-augite and also forms slender inclusions in the alkali feldspar overgrowths. Iron ore (9%) forms some early idiomorphic crystals, but mostly occurs in large laths and skeletal masses to 5 mm. long, intergrown with and moulded on other minerals. Coarse apatite prisms reach 2 mm. in length.

The mesostasis resembles type 3; it contains analcime cores, up to 1 mm. across, and rare olivine grains completely altered to serpentine.

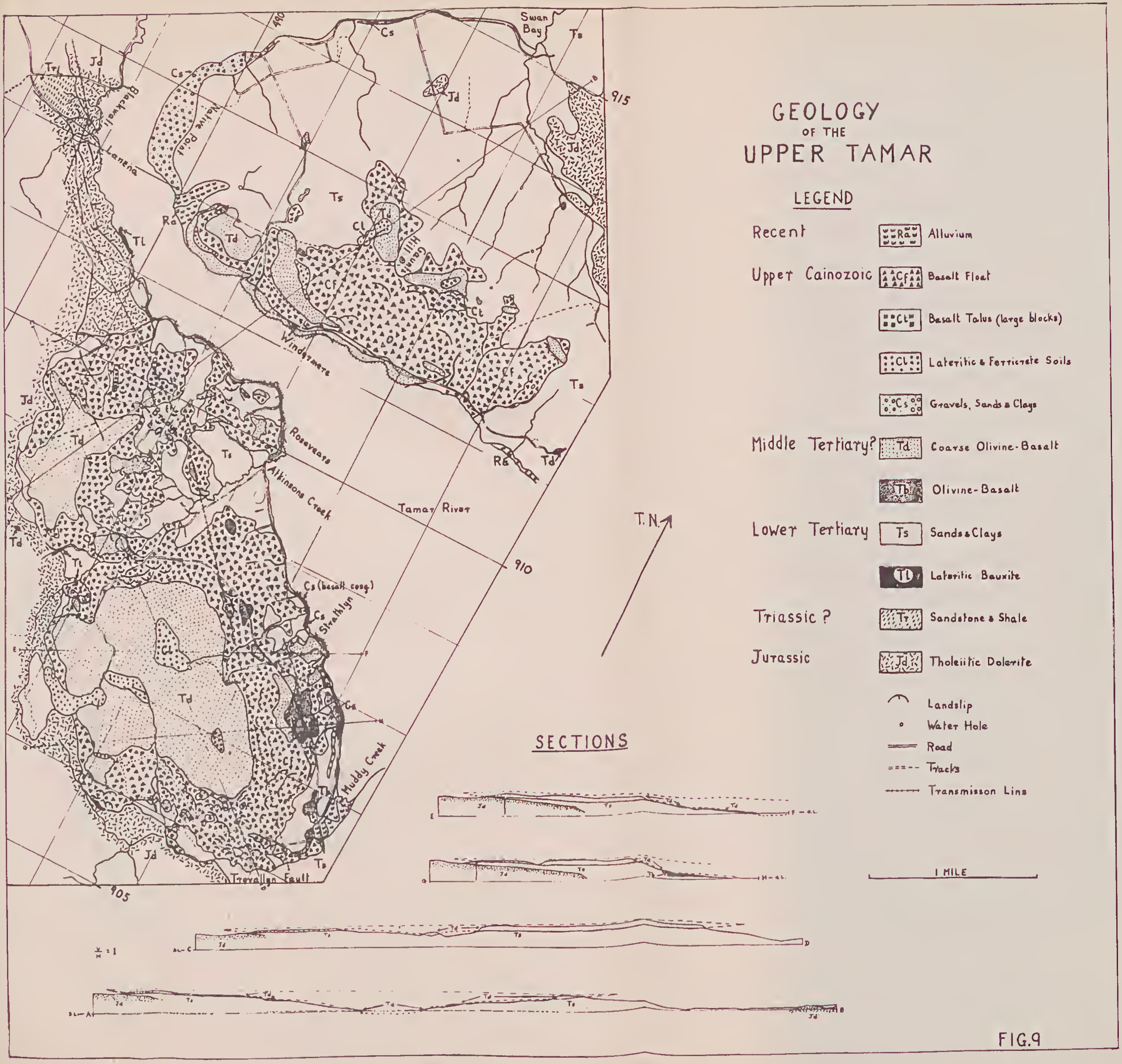

Fig. 9. Geological Map and sections, Upper Tamar area.

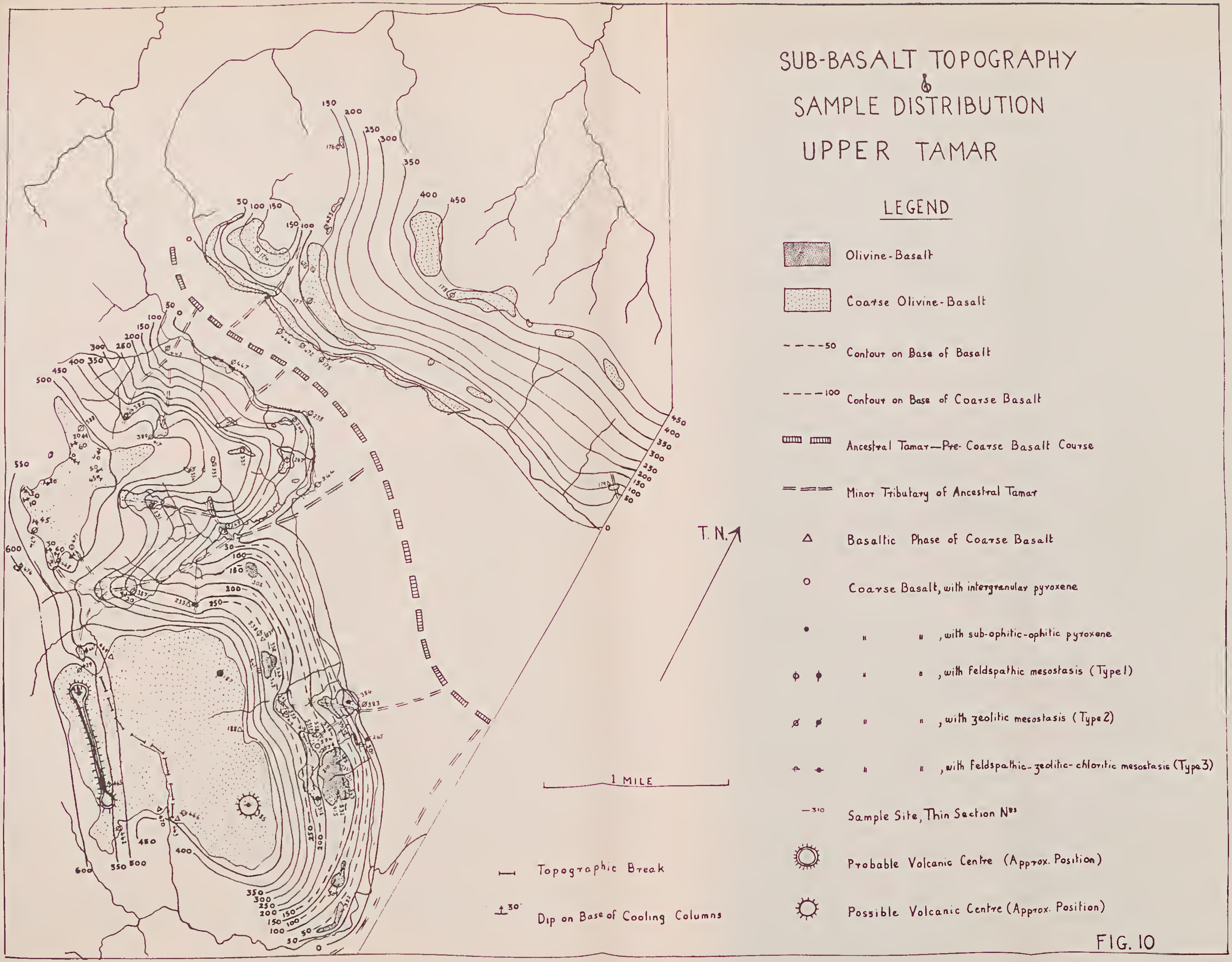

Fig. 10. Map of basal contours on basalt, Upper Tamar area.

Weathered pegmatites in the Long Reach bores contain abundant mesostasis forming over half the rock (328).

The pegmatites are near saturated alkaline rocks (analysis 13, table 1, Sutherland 1969*b*) enriched in silica, titania, soda, potash and phosphate, and impoverished in lime and magnesia, compared with the host coarse basalts.

Inclusions: An alkali(?) feldspar xenocryst, 1 cm. across, in the basalt at 8518E - 2660N, shows fused, glassy corroded borders, cracks and cleavages, largely altered to sericite and zeolites (223). The fused borders, up to 1.5 mm. wide, contain small prisms of colourless clinopyroxene, indeterminate chloritic(?) material, and vughs lined with analcime and radiating fibrous overgrowths, either a zeolite or released silica as lussatite or chalcedony. The xenocryst is surrounded by a dense outgrowth of pale mauve augite ($2V_z 61^\circ$, $Z{:}c 53^\circ$) in prisms up to 1 mm. long.

Basalt in the Long Reach bores contains rare pieces of gritty sandstone up to several inches across. Section (329) shows rounded quartz, clay and rock fragments in a pale brown isotropic matrix, paler coloured along a thin contact zone with the host rock. These inclusions probably represent Tertiary sediment, but they are not strongly indurated and may be clastic veins.

Source and Nature of the Coarse Basalt

The source is not obvious. The general distribution and basal contours (fig. 6) suggest a source under the thick capping north of Craigburn, and pegmatites here may mark an underlying feeder. If lava issued here, then it spilled south, north and west, filling the Tertiary Tamar channel. Alternatively, or in addition, lava may have erupted into the Tamar channel, ascending fault lines controlling the course of the Tamar along Long Reach, Moriarty Reach and Whirlpool Reach. The basalt extends to 100 feet below river level in the Tamar channel and its full depth, yet unproved, may be within throats of feeders.

Whether there was one voluminous outflow or separate outflows is uncertain from the available field evidence, as previously discussed. However, a flow of considerable thickness can account for several features.

1. the rocks show consistently large grain size, even against contacts, suggesting slow cooling in very thick lava.
2. they are closely similar in grain size, mineralogy and textures to coarse basalt at Mt. Cameron West, N.W. Tasmania, apparently a single flow over 500 feet thick (Sutherland and Corbett 1967).
3. they show variations in modal mineralogy and chemical composition compatible with some differentiation in a thick lava (Sutherland 1969*b*).
4. numerous pegmatites, indicating considerable volatile-rich residual fluids, are most abundant in the central channel; this suggests slow cooling within lower levels of a thick lava column. Overwhelming of an old watercourse of the Tamar with a sufficiently large volume of lava could incorporate water, without marked chilling or vesiculation by steam loss, except in relatively thin off-shoots intruding underlying sediments at contacts. Slow cooling and accumulation of residual fluids would also be likely within the throats of any underlying feeders.

The central channel occupied by the coarse basalt (fig. 6) probably represents an old channel of the Tamar, cut to well below present sea-level. However, the possibility that it is largely or in part an intrusive structure of elongate feeder channels must be borne in mind.

Formation of the basalt channel by major downwarping subsequent to extrusion is considered unlikely, as underlying sediments along the contacts dip out from the channel margins, but there may have been some contemporaneous slumping, dragging, or downsagging of sediments and lava.

Influence on Drainage

Remarkably, no major lateral or upstream diversion of the Tamar is apparent from this massive basalt effusion. This is probably explained by downsagging of the lava surface along the main channel filling, either from concomitant slumping of underlying sediments, and/or slow cooling within the channel allowing lava to drain away along this zone. When the river, dammed upstream, overtopped the basalt barrier, it would follow such surface downsags and superimpose over the basalt channel.

Alternative explanations require separate extrusions, laterally shifting the Tamar finally back to its original position, for which there is yet no direct evidence, or river capture along Moriarty Reach of one lateral by the other, which still involves superimposition over part of the main basalt channel.

The old Tamar course, preserved under the coarse basalt, turns westwards at the north end of Long Reach (fig. 6), where it may have diverted around the older flows in the lower Tamar, as previously discussed.

Age

The coarse basalt post-dates dissection of Middle Eocene sediments, of inter-volcanic gravels, and of porphyritic basalt at East Arm, correlated with the upper basalt in the lower Tamar, and apparently post-dates lateritisation of the olivine-nephelinite at Spring Bay. These facts suggest considerable erosion of the lower Tamar basalts (post-Eocene-Oligocene?), prior to eruption of the coarse basalt. The lateritic profiles on the coarse basalt resemble those of the Timboon Terrain in Victoria (Gill 1964) suggesting approximate correlation and a lower Pliocene upper age limit.

The channel occupied by the coarse basalt presumably represents an old course of the Tamar, cut following tectonic uplifting and/or major marine regression in Bass Strait. Data on the Bass Strait area (Bock and Glenie 1965; Esso Exploration Australia Inc. 1966; Ludbrook 1967; Sutherland and Corbett 1967; Kershaw and Sutherland unpubl. ms.) suggest that, within the age limits under consideration, such events occurred in Upper Oligocene and in Upper Miocene-Lower Pliocene time. This would give late Oligocene-early Pliocene age limits for the coarse basalt, with its extensive dissection favouring a late Oligocene-early Miocene age.

UPPER TAMAR

Basalts disconformably overlie Palaeocene sediments on both banks of the Tamar (figs. 9 and 10). The oldest appears to be a small flow of olivine-basalt, confined to the west bank, and is succeeded by widespread thick coarse olivine-basalt.

OLIVINE-BASALT

This rock outcrops from elevations of 300 feet down to below 50 feet on the hillslopes between Atkinson's and Muddy Creeks, and is up to

50 feet thick. It is probably more extensive than as mapped, but exposures are obscured by talus and landslips. It is dense, massive, irregularly jointed, dark bluish-grey rock and is strongly weathered in places to reddish soils associated with pisolitic ferricrete.

Petrology

Thin sections (15 slides, fig. 10) contain olivine phenocrysts in a fine grained groundmass of plagioclase, augite, some olivine, iron ore and apatite, with a glassy to zeolitic mesostasis (plate 9, Sutherland 1969*b*).

Corroded olivine (17-26%; 1.9 mm.; $2V_z$ 87-103° $\approx Fo_{92-60}$) is only slightly altered and some crystals show strain polarisation. Labradorite laths (28-47%; 0.7 mm. max.; Ab_{40}) often show corroded interiors filled with dark glass or inclusions of pyroxene and iron ore. Zoned titan-augite (29-37%; $2V_z$ $58°_{core}$ — $47°_{rim}$, Z:c 43-49$°_{core}$ — 51-54$°_{rim}$) forms sporadic microphenocrysts and rosettes, in some sections, but is mostly intergranular grains (to 0.1 mm.). Iron ore (5-11%) is scattered as squarish to circular grains (to 0.2 mm.) of titano-magnetite or ilmenite, altered to leucoxene. Apatite (2-3%) forms numerous small needles in the mesostasis.

The mesostasis (up to 28%) is clouded by crystallites of iron ore, incipient analcimisation (?) and slight chloritisation (?), and in extreme cases (310) is strongly charged with iron ore and quite dark. Interstitial and amygdaloidal zeolites include analcime, stilbite and natrolite. Rare, irregular veinlets of mesostasis cut the rock (310), and there are rare small xenoliths of sediment (243) mostly replaced by prismatic clino-pyroxene ($2V_z$ $67°_{core}$ — $58°_{rim}$, Z:c $43°_{core}$ — $51°_{rim}$).

The rock is an under saturated alkali olivine-basalt, approaching a basanite in composition (analysis 7, table 1, Sutherland 1969*b*).

Source and Age

The source is not exposed, but the basalt appears to have flowed east down towards the Tamar from the vicinity of the Trevallyn Fault line. Its age can only be fixed within wide limits; it post-dates dissection of underlying Palaeocene sediments, and its lateritised and dissected surface appears to be overlain by coarse basalt (Pre-Pliocene?).

COARSE OLIVINE-BASALT

This caps much of the area between Rosevears and Muddy Creek, and about Windermere, from elevations of 700 feet on the West Tamar and 500 feet on the East Tamar, down to below river level. The outcrops on the East and West Tamar were probably originally continuous, giving a maximum basalt thickness of about 600 feet. A basalt scarp over 100 feet high is exposed above the southern slopes of Atkinson's Creek. Whether separate flows occur is uncertain, as field relationships between outcrops are obscured by deep dissection, widespread landslipping, and similar petrological characters.

Good exposures of basal contacts are confined to cuts along the upper West Tamar Highway, but these have deteriorated. A steep contact at Brady's Lookout dips about 70° south-west, and underlying sediments are weathered and darkened over a couple of feet from the contact. Baking is slight, with no marked chilling or vesiculation at the basalt margin, and the exposure is probably the head of a small, steep lava-filled valley. Slight baking, with slight chilling and vesiculation, is typical

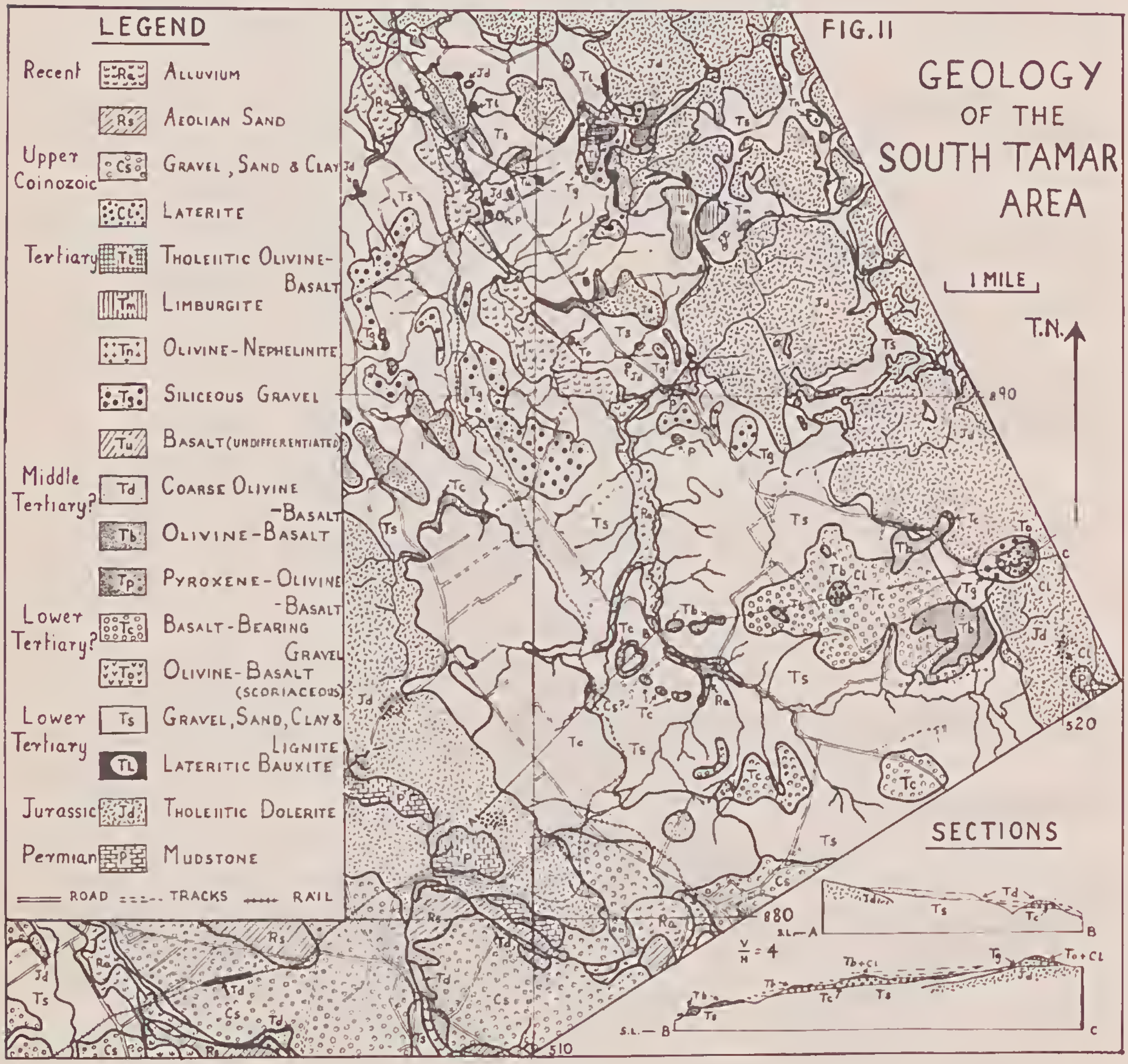

Fig. 11. Geological Map and sections, South Tamar area.

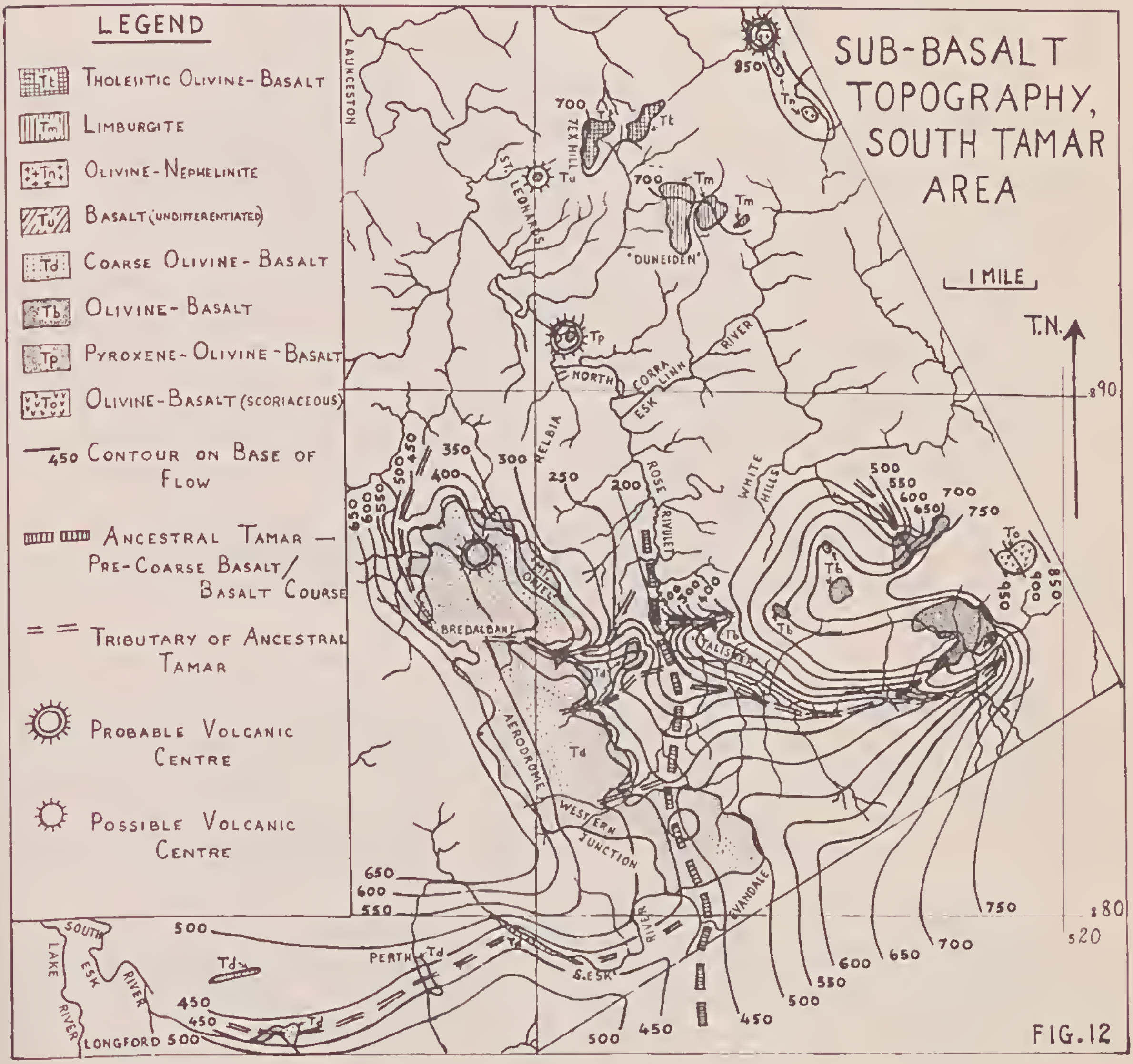

Fig. 12. Map of basal contours on basalt, South Tamar area.

of most contacts, except for some greyish chert hornfels at 9189E - 0633N.

Outcrops resemble the coarse basalt of the middle Tamar, but the rocks become finer grained near contacts; pegmatitic phases are lacking, except on the plateau above Strathlyn (9312E - 0715N). Sporadic, round amygdales near basalt margins contain analcime, natrolite, stilbite(?) and other zeolites. Cooling columns on Brady's Lookout curve down to the basalt contact in the road cut; orientations of cooling columns in this area (fig. 10) indicate that in most cases columns develop normal to the basalt base.

Petrology

Thin sections of the finer grained contact zones (17 slides, fig. 10) resemble those previously described from the underlying olivine-basalt in the Strathlyn area. However, they tend to be slightly more feldspathic and poorer in pyroxene, and lack a cloudy mesostasis and corrosion of feldspar laths. They grade into coarse basalt and a few sections (386, 416) show intermediate porphyritic textures.

The coarse basalts (43 slides) resemble those described from the middle Tamar and show similar variations in the types of mesostasis; the petrology is summarized in fig. 10. Some sections (462, 465, 471) carry pale, glomeroporphyritic augite with partly riddled interiors, and are restricted to the western margin of the basalt. The pegmatites at 9312E - 0715N (385) closely resembles pegmatites from the middle Tamar, with olivine ($2V_z$ 95-105°, β1.730 - 1.741 ± 0.002, Fo_{77-55}) and titan-augite ($2V_z$ 77°_{core} — 78°_{rim}, Z:c 45-49°_{core} — 52-58°_{rim}, β1.715 ± 0.002).

The coarse basalt grades into more feldspathic varieties, poorer in olivine, at some of the higher levels. Chemical analysis of such rock shows near saturated alkali olivine-basalt fairly high in alumina and low in magnesia, suggesting a slightly differentiated phase typical of an upper zone (analysis 8, table 1, Sutherland 1969b).

Source and Age

No feeders are exposed. However, more strongly baked sediment at 8189E - 0633N and the appearance of augite phenocrysts in the basalt along its western margin, infers effusion along a line of faulting in this vicinity (figs. 1 and 10). The basalt reaches its highest elevation on this line and a sample from this summit is noticeably enriched in mesostasis (461). Contours on the basalt base (fig. 10) suggest lava spilled from this line east towards Strathlyn and north over Brady's Lookout, filling the old Tamar channel and extending east beyond Windermere.

The coarse basalt below the 300 feet elevation near Strathlyn, on the eastern part of the plateau above the 400 feet level south of Atkinson's Creek, and in the isolated cappings at 400 feet above Windermere, may be separate and later flow or flows. These areas are marked off from the western and northern outcrops by a topographic break (fig. 10) and the pegmatite at 9312E - 0715N may mark an eruptive point, located over the Trevallyn Fault line near the likely centre for the oldest olivine-basalt at Strathlyn.

The precise age of the coarse basalt is difficult to fix. It was erupted following considerable dissection and weathering of the underlying Lower Tertiary sediments. The underlying olivine-basalt at Strathlyn also appears to have been weathered, lateritised and dissected before eruption of the coarse basalt. There is considerable resemblance to the coarse basalt of the middle Tamar, in occupation of a channel cut to below present river level and in degree of subsequent dissection and development of lateritic profiles. This suggests approximate contemporaneity and hence late Oligocene-early Pliocene age limits.

SOUTH TAMAR

SCORIACEOUS OLIVINE-BASALT

This flow remnant caps a small hill on the Blessington Road, three miles E.S.E. of White Hills at 900-990 feet in elevation. It overlies siliceous waterworn gravels and slopes down to the north-east. The capping is 60-70 feet thick and is largely lateritised scoriaceous basalt, with a deep kaolinised and bauxitised lower profile.

Petrology

Fresh basalt only occurs at road level on the north side, and sections (274, 378) show a vesicular basalt containing olivine in an intergranular to subophitic groundmass of labradorite, augite, iron ore and a little mesostasis.

Corroded olivine (10-12%; 1.3 mm. max.) is heavily altered to ferruginous material. Labradorite (37-43%) forms laths and plates (to 0.9 mm.), zoned from about Ab_{38} to Ab_{54}. Augite (36-39%) occurs in almost colourless, zoned crystals (to 0.7 mm.). Iron ore (5-7%) forms squarish to irregular grains and lath like rods (rarely to 0.5 mm.). The mesostatis (6-11%) is a colourless to pale grey or brown glassy, feldspathic residue, slightly clouded with globules of iron ore.

The rock resembles a near saturated alkali olivine-basalt, but the paucity of fresh rock precludes accurate determination.

Source and Age

The source is unknown, but the basal slope suggests an origin to the west, providing that no later tectonic tilting took place from this direction. The basalt appears to be an old lateritised residual, younger than the Palaeocene-Eocene beds of the area, but older than the inter-volcanic gravels to the west, as these contain fragments of similar basalt. The available evidence thus gives tentative Eocene to mid-Tertiary age limits.

THOLEIITIC OLIVINE-BASALT

Remnants of this flow cap 7EX Hill above St. Leonards, overlying siliceous conglomerates and sands at elevations of about 700 feet. The basalt is 20-30 feet thick, with a scoriaceous base passing up into more massive basalt. Baking of underlying sediments is slight and a petrographic description of a contact sandstone is given in Longman *et. al.* (1966)

Petrology

Thin sections (6 slides) show several variations. Massive basalt (173) contains olivine and plagioclase in an abundant hyaloophitic black mesostasis (plate 11, Sutherland 1969*b*).

Olivine (13%; $2V_z 88\text{-}99^\circ \approx Fo_{91-67}$) forms corroded, fresh, glomeroporphyritic phenocrysts and scattered granules (to 1.8 mm.). Labradorite

(33-43%; $\approx Ab_{40}$) forms skeletal laths and plates (to 1.2 mm.). The remainder of the rock is an opaque glass containing numerous elongate crystallites and radiating sheaves of plagioclase and clino-pyroxene, and a little greenish-yellow opal and chalcedony. This rock matches the Ouse Type (Edwards 1950; McDougall 1959) and grades into slightly vesiculated rock.

In this variety (208), olivine (to 2.3 mm.) show slight alteration to opal and carbonate, labradorite laths rarely exceed 0.3 mm. long, and pale granular augite (19-23%; Z:c 44_{core}—46^{o}_{rim}), is crystallised in the mesostasis (25%). Vesicles contain opal, chalcedony and carbonate, and the rock resembles the Bridgewater and Pontville types (McDougall 1959).

Strongly vesicular varieties (172, 420) are similar, but the dark mesostasis has largely crystallised. These rocks contain olivine (12%), zoned labradorite (39-44%), intergranular to subophitic augite (32-37%), small irregular grains and laths of iron ore (4-6%) and brownish-grey mesostasis clouded with crystallites (4-9%). These approach the Jordan type (McDougall 1959).

The rock is saturated olivine-basalt with low alkalies (analysis 18, table 1, Sutherland 1969*b*), typical of tholeiitic types.

Source and Age

The feeder position is obscure. Basalt 400 feet below 7EX Hill (Longman *et. al.* 1964) was exposed in a swimming pool excavation (Dr. K. Burns pers. comm.). The excavation went through soil, clay, then weathered basalt with fairly regularly shaped joint blocks, and at nine feet passed into clay containing ferruginised fossil tree trunks. No basalt is now visible at the site and its precise relationships to the 7EX Hill flow cannot be determined. However, its restricted occurrence and position makes it a possible eroded feeder for the flow.

The flow overlies Palaeocene-Eocene beds, but other field evidence for its age is lacking.

LIMBURGITE

Small cappings of this rock outcrop above "Duneiden" farm, less than a mile S.W. of the 7EX Hill flow and at a similar elevation of 700 feet. The flow is 20-30 feet thick and is moderately vesicular towards the base.

Petrology

Thin sections (206, 207) show olivine, augite and iron ore in a dark glass (plate 12, Sutherland 1969*b*).

Fresh, corroded olivine (14-19%; 2 mm. max., mostly to 1 mm.; $2V_z$ 88-$99^{o} \approx Fo_{91-67}$) includes some crystals with strain polarisation and translation lamellae. Zoned, prismatic augite (37-42%; to 0.5 mm.; Z:c 44-49^{o}_{core}—49-55^{o}_{rim}) shows faint brown to mauve pleochroic margins. The base is hyaloophitic to hyalopilitic purplish-brown glass, containing small squarish grains and lath-like iron ore crystallites (to 0.1 mm.), sporadic pale yellow opal, and vesicles lined with opal and chalcedony.

It is strongly under saturated rock, fairly low in alumina and alkalies (analysis 17, table 1, Sutherland 1969*b*).

Source and Age

The source is unknown, but the close association and similarity in outcrop to the 7EX Hill flow, suggests possible eruption from a related centre. The flow overlies Palaeocene-Eocene sediments, but there is little other field evidence of its age.

OLIVINE-NEPHELINITE

A small flow of this rock overlies Jurassic dolerite and Tertiary sediments, three miles N.E. of St. Leonards, at elevations around 900 feet. The flow is up to 50 feet thick, with laterite remnants. It is dense, bluish-grey, fine-grained rock containing amygdales, and small xenoliths of dolerite and rare peridotite in the cut on the Scottsdale Highway.

Petrology

Thin sections (6 slides) show olivine phenocrysts in a groundmass of augite, olivine, iron ore and a glassy and feldspathoidal mesostasis. Some sections contain rare dolerite xenoliths, pyroxene xenocrysts and peridotite fragments.

Corroded olivine (13-18%; 2.5 mm. max.; $2V_z 86-97^{o} \approx Fo_{94-74}$) shows slight alteration to chloritic and "bowlingitic" materials, and some crystals show strain polarisation and translation lamellae. Titan-augite (37-46%) forms prismatic microphenocrysts and grains (to 0.7 mm.). Iron ore (7-10%) is dispersed as minute squarish to irregular grains (to 0.5 mm.); rare larger clots (to 2 mm.) sometimes show cores of brownish-green spinel (211) and represent altered xenocrysts. Apatite (2-3%) forms elongate prisms (to 0.5 mm.) and minute needles in the mesostasis.

The mesostasis (14-25%) is hyalopilitic glass, slightly clouded in patches with iron ore crystallites, and contains poikilitic areas of nepheline up to 2 mm. across. Amygdales are commonly lined with natrolite. Dolerite xenoliths (to 5 cm.) show mineralogy and textures typical of the Jurassic dolerite bedrock of the area, but the mesostasis is fused to pale yellow or dark brown glass. Rare corroded clino-pyroxene xenocrysts, derived from the dolerite xenoliths, and clino-pyroxene exposed on the edges of xenoliths, are overgrown with titan-augite. The margins of some dolerite xenoliths (339) contain pockets of natrolite and skeletal nepheline (to 0.5 mm.) filled with dark glass.

The rock petrologically resembles some sections of the olivine-nephelinite at Spring Bay in the middle Tamar, and is probably similar in chemical composition.

Source and Age

The eruptive point is probably marked by the occurrence of dolerite xenoliths at the north end of the flow. This point also lies on the projected intersection of north-westerly and north-easterly fault or strong joint lineaments, mapped nearby (Longman *et. al.* 1964).

The flow overlies sediments that probably represent an extension of the Palaeocene-Eocene beds to the west, and it has been lateritised; further field evidence of its age is lacking.

PYROXENE-OLIVINE-BASALT

A small outcrop of this rock overlies Lower Tertiary sediments, between 100-130 feet elevations, on the bank of the North Esk, 1¼ miles N.E. of Corra Linn bridge. Cooling columns in the basalt incline normal to the base, which dips down towards the river. The basalt is massive, darkish-grey, and is speckled with numerous inclusions which project roughly on weathered surfaces. These are prominently black, vitreous pyroxene crystals to over 2 cm., commonly with reaction borders, and dolerite fragments to over 20 cm., sometimes with small irregular veinlets of fused material on the margins. Rare small peridotite and fused sedimentary xenoliths are present.

Petrology

Thin sections (9 slides) show xenoliths and xenocrysts scattered amongst phenocrystal olivine and augite in a groundmass of plagioclase, augite, olivine, iron ore and a fairly abundant hyaloophitic to intersertal mesostasis (plate 10 Sutherland 1969*b*).

Corroded olivine (11-17%; 0.05-3.5 mm.; $2V_z 86-99^\circ$-Fo_{94-67}) sometimes includes iron ore, and some large crystals show strain polarisation and translation lamellae. Colourless augite (4-11%) forms corroded cores and resorbed borders, with overgrowths of titaniferous augite in euhedral to subhedral crystals (0.5 mm. - 2 cm., but mostly 1-5 mm.). The cores ($2V_z 50-56^\circ$, Z:c $47-49^\circ$, $\beta 1.698-1.700 \pm 0.002$; analysis 1 and 2, table 2, Sutherland 1969*b*) are more or less optically continuous with the spongy recrystallised borders ($2V_z 50-62^\circ$, Z:c $44-52^\circ$; analysis 3, table 2, Sutherland 1969*b*). The borders reach over 2 mm. wide, contain small inclusions of corroded olivine and rare trains of fresh augite, and sometimes show rough concentric layering due to different degrees of resorption. In smaller crystals the core is generally completely resorbed. The overgrowths, up to 0.4 mm. wide, are composed of the normal augite of the groundmass (analysis 4, table 2, Sutherland 1969*b*). They show narrow zoning, sometimes oscillatory, and a general change from colourless augite on the inside to pleochroic titaniferous augite on the outside. They tend to build out in prismatic extensions and cleavages tend to be continuous across the overgrowth; some show slight corrosion riddling.

Labradorite (24-35%) forms laths and plates (1.5 mm. max., mostly to 1 mm.) zoned from about Ab_{37}. Some laths have slightly hollowed interiors and larger laths show slight flow alignment. Titaniferous augite (26-31%) forms overgrowths, microphenocrysts and rosettes (mostly 0.3-0.5 mm.), smaller groundmass grains, and rare corroded phenocrysts (to 2 mm.) containing inclusions of groundmass minerals. The augite is colour zoned (X, Y mauve, Z brownish-yellow), generally showing more intensely coloured and pleochroic outer zones ($2V_z 54-66^\circ_{core}$ — $65-72^\circ_{rim}$, Z:c $45-54^\circ_{core}$ — $54-61^\circ_{rim}$), but sometimes showing paler outer zones ($2V_z 59-66^\circ_{core}$ — $41-53^\circ_{rim}$, Z:c $47-49^\circ_{core}$ — $41-42^\circ_{rim}$). Iron ore is dispersed in squarish to irregular grains mostly to 0.05 mm.).

The glassy mesostasis (12-23%) is darkened with crystallites of iron ore and contains sporadic patches of carbonate and zeolites. Late-stage plagioclase plates in the mesostasis enclose augite and apatite needles and intergrow with crystallites along their borders.

Dolerite xenoliths, typical of the Jurassic dolerite bedrock, appear to have partially melted on incorporation, fusing their normal mesostasis. In sections (563, 564) pyroxene and plagioclase in the xenoliths in contact with this mesostasis tend to be corroded, and many clino-pyroxenes show fritted, riddled margins. Whisps and fibrous sheaves, in the mesostasis and bordering some pyroxenes, appear to represent incipient crystallisation of ortho-pyroxene, some clino-pyroxene and sillimanite or mullite(?). The mesostasis includes feldspar and iron ore relics and is charged with granular iron ore, passing into opaque black glass. It contains sporadic amygdales with analcime, natrolite and other zeolites, rare groups of skeletal tablets of alkali feldspar (sanadine?), and patches of chalcedony, partly fringed with lussatite and showing curved fracture reminiscent of cristobalite (563). Clear to pale yellow or brown, partly devitrified, feldspathic glass forms around fused ends of plagioclase laths projecting into the mesostasis; this sometimes contains small elongate prisms of colourless clino-pyroxene. Scattered xenocrysts of clino-pyroxene (with incipient chloritisation) and plagioclase (with fused glassy borders partly replaced with colourless clino-pyroxene) in the basalt host are probably derived from the dolerite xenoliths.

Rare peridotite xenoliths (562) contain olivine ($2V_z 86-97^\circ \approx Fo_{94-74}$) showing translation lamellae, some colourless clino-pyroxene ($2V_z 63-66^\circ$; $Z:c 48-50^\circ$) and minor plagioclase ($\approx Ab_{35-55}$). Rare xenocrysts (to 8 mm.) of grey, brown or olive-green spinel (analysis 5, table 2, Sutherland 1969*b*) are marginally altered to opaque iron ore. Sparse large clots of opaque iron ore in the basalt probably represent completely altered spinel xenocrysts and are sometimes overgrown with titaniferous augite. Rare, small glassy xenoliths, up to 2 mm. across, may represent Tertiary sediment fused to brownish or colourless glass, bordered and replaced by clino-pyroxene.

The rock is an under saturated alkali olivine-basalt, with a fairly high lime and magnesia and low alkali content (analysis 9, table 1, Sutherland 1969*b*); this presumably reflects the abundance of augite megacrysts. Analyses of the augites show that cores have higher alumina and soda and lower calcium, compared with reactions rims and overgrowths, suggesting crystallisation at depth (analysis 1 - 4, table 2, Sutherland 1969*b*). There is also an increase in titanium, correlating with coloration in overgrowths compared with cores and reaction borders.

Source and Age

The outcrop of the basalt, with the inclusion of numerous partially melted xenoliths of country rock, as well as augite megacrysts, suggests an eroded plug.

The basalt post-dates adjacent Palaeocene-Eocene beds. Its isolation indicates considerable subsequent erosion, but further field evidence of age is absent.

OLIVINE-BASALT

Isolated remnants of this rock occur south of White Hills and east of Rose Rivulet. The basalt descends from about 750 feet elevation on the east to 200 feet near Talisker Farm, where it shows its maximum thickness of about 100 feet. It disconformably overlies inter-volcanic conglomeratic beds and Palaeocene-Eocene sediments. A contact in the quarry above Talisker Farm dips very steeply west, with slight baking of the underlying sediments.

The basalt is massive, but in places carries sporadic amygdales commonly containing natrolite and other zeolites. Inclined cooling columns are exposed in the quarry at Talisker Farm, and at one point form "synclinal" structure. A deeply weathered outcrop at 750 feet at 1580E - 8650N appears to represent a lateritised remnant of the basalt (Woodstock B surface; Nicolls 1960).

Petrology

Thin sections (19 slides) show olivine and augite phenocrysts in a groundmass of plagioclase, augite, iron ore, minor olivine, and glassy mesostasis.

Corroded olivine (16-24%; 2 mm. max., mostly to 1 mm.) is slightly glomeroporphyritic. Titaniferous augite (28-37%) forms glomeroporphyritic phenocrysts, rosettes and intergranular grains (to 1.2 mm.) and is colour zoned (Z:c $44\text{-}50^{\circ}_{core}$ — $48\text{-}54^{\circ}_{rim}$). Laths and anhedral plates of labradorite (to 1 mm.) are zoned from Ab_{38} and show some flow alignment. Iron ore (4-8%) is dispersed in squarish to irregular grains (mostly to 0.1 mm.), or as lath-like crystallites in the mesostasis. Apatite (2%) forms numerous needles in late-stage plagioclase and in the mesostasis.

The mesostasis (up to 20%) is an intersertal to almost hyalopilitic, glassy residue, generally clouded with crystallites. In some sections (195, 201, 202, 218, 280, 283) it is largely crystallised to interstitial zeolites (including analcime), with minor nepheline(?) and biotite, but in others (212, 280, 288, 380) it passes into brownish glass. Sporadic amygdales contain zeolites, calcite and a little greenish clay or chalcedony.

Small xenoliths of Tertiary sediment (283, 291, 296) are commonly fused to clear or brownish glass, partly replaced with prismatic, colourless clino-pyroxene. Some xenoliths develop envelopes of brownish glass interspersed with the host rock. Rare, resorbed pyroxene xenocrysts (372) to 4 mm. across, are largely replaced with exsolved plates of colourless augite ($2V_z 56^{\circ}_{core}$ — 53°_{rim}) and partly overgrown with titaniferous augite ($2V_z 51^{\circ}_{inside}$ — $56^{\circ}_{outside}$).

The basalt resembles the host Corra Linn basalt, but lacks the numerous augite megacrysts, and also resembles the lower olivine-basalt at Strathlyn in the upper Tamar. It is an under saturated alkali olivine-basalt, approaching a basanite in composition (analysis 10 and 11, table 1, Sutherland 1969*b*). The dark, glassy mesostasis-rich variety (analysis 11) is slightly enriched in iron oxide and soda at the expense of alumina, lime and potash, compared with the more typical rock (analysis 10).

Source and Age

The basalt flowed into a small steep valley near Talisker Farm, but its precise source is uncertain. It may represent an isolated branch of the coarse basalt flow erupted from Cocked Hat Hill, but it is possibly an earlier eruption, as discussed under inter-volcanic sediments, and its highest point at Currachmore Farm slightly exceeds the elevation of Cocked Hat Hill. This suggests a separate eruption, which flowed west from the vicinity of Currachmore Farm. A further alternative is eruption from the plug at Corra Linn, with lava flowing south towards Currachmore Farm and then west down to Talisker Farm.

The basalt post-dates dissection of the Palaeocene-Eocene sediments and overlying inter-volcanic conglomerates. The apparent deep weathering and lateritisation of the basalt at 1580E - 8650N suggests an early Pliocene upper age limit, based on arguments of Nicolls (1960) and dating of similar profiles in Victoria (Gill 1964). Within these limits, the dissection of the underlying beds, based on stratigraphic relationships in the area and on the known history of Bass Strait (as discussed for the middle Tamar area), was most likely in the Upper Oligocene or Upper Miocene-Lower Pliocene. This gives late Oligocene-early Pliocene age limits for the basalt.

LOWER TAMAR	MIDDLE TAMAR	UPPER TAMAR	SOUTH TAMAR	
Dune sands, talus, alluvium.	Talus, alluvium	Alluvium, talus, basalt gravel.	Windblown sands, talus, alluvium.	
Disconformity, ferricrete.	Disconformity, ferricrete.	Disconformity, ferricrete.	Disconformity, ferricrete.	
Siliceous sands and gravels 250+ ft.	Siliceous sands and gravels 150+ ft.	Siliceous sands and gravels 40+ ft.	Siliceous sands and gravels. 30+ ft.	
Disconformity, laterite(?).	Disconformity, laterite.	Disconformity, laterite.	Disconformity,	olivine-nephelinite 50+ ft.
Olivine-basalt 45+ ft.	Coarse olivine-basalt 400+ ft.	Coarse olivine-basalt 500+ ft.	Sands, clays and gravels 100+ ft.	
Sands 2+ ft.	Nepheline basanite(?) 10+ ft.	Disconformity, laterite (?)	Disconformity, laterite(?)	
Disconformity.	Disconformity, laterite(?).	Olivine-basalt 50+ ft.	Coarse olivine-basalt 400+ ft.	
Olivine-basalt 210+ ft.	Olivine-nephelinite 50+ ft.			limburgite, 30+ ft.
Disconformity.	Disconformity(?)	Disconformity	Basalt tuff(?).	
Clays, sands and lignites 287+ ft.	Porphyritic olivine-basalt (?) 10 ft.	Clays, sands, lignite and gravels 600 ft.	Gravel(?) 6+ ft.	
Disconformity	Dolerite gravels 50+ ft.	Disconformity, bauxite.	Disconformity.	
Dolerite basement.	Disconformity.	Dolerite basement	Olivine-basalt 100 ft.	
	Clays, sands, gravels and lignites 800+ ft.		Pyroxene-olivine basalt 15 ft.	
	Disconformity, bauxite.		Disconformity. ?	
	Dolerite basement.		Dolerite gravels, sands and clays 150 ft.(?)	Tholeiitic olivine basalt, 30+ ft.
			Disconformity	
			Scoriaceous olivine-basalt 60 ft.	
			Clays, sands, gravels and lignites 900 ft.	
			Disconformity, bauxite.	
			Dolerite basement.	

TABLE 1.

Stratigraphic Successions, Tamar Trough, showing probable correlations.

COARSE OLIVINE-BASALT

Coarse basalt outcrops west of Rose Rivulet from Breadalbane to Evandale and in isolated exposures in the Perth-Longford area. It disconformably overlies inter-volcanic conglomeratic beds and underlying Palaeocene-Eocene sediments. It is partly buried by probable Tertiary beds and younger siliceous sands and gravels.

The basalt base overlaps Jurassic dolerite on its western margin at elevations between 500-630 feet and descends to 300-350 feet on its eastern margin. The highest point on the basalt forms Cocked Hat Hill at 725 feet, indicating a maximum flow thickness of at least 200 feet, and possibly up to 425 feet.

The basalt is massive, develops cooling columns in places, and in parts is strongly decomposed and granular in appearance. There are sporadic amygdales and in a small cut below Mt. Oriel Farm these contain natrolite. Scoriaceous basalt tuffs are recorded below the basalt in railway excavations at Breadalbane and a coniferous forest flora overwhelmed in the tuff is listed (Johnston 1874, 1875, 1888), but these exposures are now covered.

Petrology

In thin sections (17 slides) the rocks are mostly medium grained and similar to coarse basalts described from the middle and upper Tamar areas, but no marked picritic and pegmatitic varieties were noted. The titan-augite in the rocks is predominantly intergranular, with little development of subophitic to ophitic texture, and the mesostasis is mostly types 2 or 3. The coarsest rock (213) forms the summit of Cocked Hat Hill, and is a feldspathic, olivine-poor variety compared with some of the rocks from lower levels, suggesting an upper differentiated zone. Near the base the basalt grades into fine grained rock (165, 216, 300, 578, 579) petrologically similar to the olivine-basalt east of Rose Rivulet, but in places a medium grain size is maintained to the basal contact (379).

Petterd (1902) gives a microscopic description of a hydrated olivine-basalt, resembling 'palagonite' in appearance, found in sinking holes at Native Point, Perth, but no exposures of this rock were found by the present author. Its precise relationship to the coarse basalt outcropping along the river bank below Native Point Farm is uncertain, but it may be a weathered form.

Source and Age

Johnston (1888) considered that the eminence of Cocked Hat Hill formed the principle eruptive vent for the Breadalbane flow, and he recorded tuffs nearby. A recent regional gravity survey indicated the eixstence of a large dyke extending to depth below Cocked Hat Hill (M. J. Longman and D. E. Leaman pers. comm.)

The eruption of thick lava here may have blocked the old Tamar at Evandale (fig. 12), diverting it through Longford via the gorge to Launceston and forming the South Esk (Carey 1946). However, much of the lava extends upstream from the probable eruptive point of Cocked Hat Hill. Unless there has been extensive removal of basalt downstream, this may mean that the Tamar was already diverted through Longford by another of the lavas in the area, prior to effusion of the coarse basalt.

The coarse basalt post-dates dissection of Palaeocene-Eocene sedi-

TABLE 2. Proposed Cainozoic History of the Tamar Trough

Age	No.	Event
--?-- UPPER OLIGOCENE-PALAEOCENE	(1)	Epeirogenic uplift with vertical faulting and tilting forming the Tamar Trough.
	(2)	Dissection (with bauxitisation?) of Jurassic dolerite basement and formation of main Tamar drainage system.
	(3)	Deposition of non-marine clays, sands, gravels and lignites, with intervals of erosion and lateritisation (and possible minor volcanic activity). Tamar channel cut to 65+ feet below present sea level in the lower Tamar.
--?-- MIOCENE - UPPER OLIGOCENE (?)	(4)	Eruption of olivine-basalt into the lower Tamar (and possible lava eruptions in the south Tamar). Possible diversion of the Tamar, west through Beaconsfield between West and Badger Heads.
	(5)	Dissection, with deposition of dolerite gravels, sands and clays in the lower, middle and south Tamar.
	(6)	Eruption of olivine-basalt at East Arm, flowing into the lower Tamar. Possible dissection.
	(7)	Eruptions of olivine-nephelinite, basanite and alkali olivine-basalt in the middle, upper and south Tamar, with intervening dissection and lateritisation (?).
	(8)	Eruptions of thick flows of coarse alkali olivine-basalts in the middle, upper and south Tamar areas, filling the Tamar channel to well below present sea level in the middle and upper Tamar. Diversion of the Tamar through Longford as the South Esk (or already diverted) and possible rediversion of the Tamar eastwards at Long Reach through the Tamar Heads. Eruptions possibly continue into the Pliocene.
	(9)	Possible deposition of sands and gravels on some basalts at higher levels related to Miocene marine transgression in Bass Strait.
--?-- PLIOCENE	(10)	Dissection, with entrenchment of Tamar following marine regression in Bass Strait.
	(11)	Lateritisation of valley profiles forming the Woodstock surface.
	(12)	Dissection and deposition of fluviatile beds containing basalt and laterite fragments at Perth.
--?-- QUATERNARY	(13)	Dissection by Tamar drainage in lower reaches to below sea level during Glacial low seas. Drowning of Tamar mouth during Interglacials, with deposition of siliceous sediment and formation of terrace levels associated with the high marine stands. Development of levels at 200-250 feet (possibly a Tertiary level), 90-100 feet, 60-70 feet, 40-50 feet, 30 feet and 10-15 feet above M H W S around Tamar mouth. Development of ferricrete and other soils. Extensive land slippages forming large talus deposits below basalt cappings.
	(14)	Deposition of windblown littoral and inland sand. Deposition of estuarine sediments associated with establishment of the Post-Glacial sea. Development of coastal beach ridges at Tamar heads. Recent slight recession of estuary level (?) giving present deposition of estuarine and fluviatile alluvium. Deposition of current erosive and land slip debris.

This Table incorporates some further palynological dates on the Tamar Trough sediments from samples submitted to the South Australian Department of Mines since the main part of the script was written. Carbonaceous clays from just beneath the basalt flow exposed in the Launceston Port Authority excavation project at Garden Island (at -35 feet below A.L.T.) and from under the basalt in the Tasmanian Mines Department Tamar Avenue Bore, Georgetown (at +15 to -8 feet S.L.), yield Mid-Tertiary assemblages containing *Cyatheacidites annulata*, and the look of the Georgetown assemblage appears to be older than Longfordian in age. (W. K. Harris, pers. comm.). This suggests an Upper Oligocene age for these non-marine beds, which is consistent with their relatively low position compared with known deposits of the Lower Miocene marine transgression on northern Tasmania. These are the youngest sub-basaltic beds yet identified in the Tamar Trough and they probably represent deposits associated with and dating the Tamar channel prior to its occupancy by the lower olivine-basalt.

ments and inter-volcanic gravels, and possibly post-dates the olivine-basalt east of Rose Rivulet (late Oligocene-early Pliocene). Its decomposed surface is overlain by probable Tertiary sediments at Perth, indicating Mid to Upper Tertiary age limits and an approximately comparable age to the coarse basalts in the middle and upper Tamar areas.

DISCUSSION

The Tamar volcanism and its relationships to the Cainozoic history of the Tamar Trough, as deduced in this study, is summarized in table 2. One feature is the apparent absence of Miocene marine or littoral sediments within the Trough, an expected inlet for the major Miocene marine transgression recorded elsewhere in northern Tasmania and south-eastern Australia (Ludbrook 1967). Such deposits may have been removed by subsequent erosion, but a possible explanation is that in the Miocene the northern end of the Tamar Trough was blocked with sufficient thickness of basalt to prevent access by the sea.

The volcanism of the Tamar Trough is essentially representative of the alkaline volcanic associations in Tasmania (Sutherland 1969*a*, 1969*b*), but minor tholeiitic extrusion occurs in the south-eastern end. Preliminary investigations of the Tertiary volcanic rocks in adjacent areas (Sutherland 1968, 1969*c*) show that the Tamar Trough falls within an alkaline volcanic association extending east to the Devonport-Sheffield area, but passes into a zone of tholeiitic basalts to the east and south from Pipers Head to Campbell Town.

The general alkaline volcanic sequence, suggested by the stratigraphy of the Tamar Trough, shows initial extrusions of near saturated alkali olivine-basalt, followed by more alkaline under saturated lavas of olivine-nephelinite, then under saturated alkali olivine-basalts and basanite(?), and finally massive effusions of under saturated to near saturated coarse alkali olivine-basalt. Whether such successions are typically developed in the alkaline volcanic associations in Tasmania has yet to be resolved, pending more detailed work in other areas. However, the proposed Tamar succession closely compares with a sequence established in the Older Volcanic Series alkaline association of Victoria at Bacchus Marsh (Jacobson and Scott 1937). Flows tend to be thinner and more numerous, and olivine-nephelinites are more prominent, in the Bacchus Marsh sequence, but a similar genesis and magmatic history is suggested for the two sequences, with some differences in the eruptive pattern.

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